The Impact of COVID-19 on Commodity and S&P 500 Sector Return Volatility

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We investigate the impact of COVID-19 on commodity return volatility. We find that the impact of COVID-19 on return volatility is different across different markets. Unlike S&P 500 sector indices, commodity return volatility is less sensitive to the impact of COVID-19. The impact of vaccination programs on return volatility is weak for both commodity and financial markets. We employ Fama-French 3 Factor Model and APARCH (1,1) for return volatility estimation. The variation in COVID-19's impact across different markets has an important implication for return volatility hedging.

Keywords: COVID-19, commodity, return volatility, sector indices, hedging, vaccination

INTRODUCTION

The COVID-19 pandemic was one of the largest negative shocks to the US economy and financial markets in U.S. history. During 2020, the S&P 500 dropped significantly, and the overall volatility of financial markets was extremely high. Prior studies document varying impacts of COVID-19 across financial markets. In particular, Curto and Serrasqueiro (2021), find some S&P 500 subsectors were more heavily impacted than others. While many researchers investigated the impact of COVID-19 on financial markets, there remains a lack of empirical analyses on the impact of COVID-19 on commodity returns.

This study analyzes the impact of COVID-19 on the volatility of the financial and commodity markets with the following research questions:

- 1. Does COVID-19 affect the return volatility of commodities?
- 2. Does the size and direction of COVID-19's impact vary across different commodities?
- 3. Is the impact of COVID-19 on return volatility different across different markets?

To answer these questions, we will be analyzing commodity market return data ranging from energy, precious metals, industrial metals, and agriculture markets (Gold, Silver, Crude Oil, Natural Gas, Lumber, Wheat, Live Cattle, and Aluminum), as well as the eleven industry sectors that form the S&P 500 index:

(Information Technology, Health Care, Financials, Consumer Discretionary, Communication Services, Industrials, Consumer Staples, Energy, Utilities, Real Estate, and Materials).

Literature Review

Curto and Serrasqueiro (2021) measured the impact of COVID-19 on the volatility of the S&P 500 indices and FATANG stocks. They found that some subsectors of the S&P 500 reacted more to COVID-19 than others, but all the subsectors followed the same path. Volatility increased during the COVID-19 period and decreased with the introduction of the vaccine.

Baek (2020) found that negative news regarding the number of deaths is twice as impactful as positive news regarding recoveries, suggesting a negativity bias. Gao (2022) found when stock market volatility was high, COVID-19 imposed a stronger effect on stock market volatility. Anderson (2022) argues that there could be more factors to consider during this time period. Inflation, bearish markets since 2008, and Russia's invasion of Ukraine are all factors that are not considered when looking at asset returns through the COVID-19 lens.

Bakas (2020) found volatility in the oil market is significantly reduced when uncertainty about pandemics rises, with the effect remaining negative and statistically significant for about a year after the uncertainty shock. The effect on the gold market is positive but less significant.

Contribution

Our research adds three contributions beyond the findings of Curto and Serrasqueiro (2021). First, we examine the commodity return volatility during the pandemic along with the eleven S&P 500 indices. By including a less volatile market than the FATANG stocks (Facebook, Amazon, Tesla, Apple, Netflix, and Google), we will see if there are statistically significant differences in how these two markets reacted to COVID-19.

Second, after replicating Curto and Serrasqueiro (2021) using the APARCH (1,1) model, we use the Fama-French 3-Factor Model (FF3) to determine the statistical significance of their findings. The Fama-French 3-factor model includes value stock and small cap outperformance (Fama and French, 1993). The three factors included in this model are: the size of the firms, the book-to-market value, and excess return on the market, which are used to help determine market returns. While the APARCH (1,1) AR (4) model to estimate asset returns is autoregressive, the FF3 model argues that the market does not have any previous return memory because it is efficient. The addition of the FF3 model will help contribute an additional level of statistical significance to our research question.

Our third contribution deals with our findings from this study which will be further described throughout this paper. We find that there is an important takeaway when looking at return volatility hedging. During the pandemic, commodity return volatility was not strongly correlated with stock return volatility. Therefore, we can infer that commodities can be used as reasonable instruments for return volatility hedging.

Methodology

Process

To replicate the APARCH (1,1) model, we downloaded the S&P 500, S&P 500 indices, and commodity market data. Following Curto and Serrasqueiro (2021), Table 1 contains summary statistics, Table 2 contains a time lined growth analysis, and Tables 3 and 4 contain correlations between variables before and after COVID-19. We input the data into *Stata* Data Software Package to compute our empirical results. We first replicated the APARCH (1,1) AR (4) model to estimate asset returns which is represented by:

$$r_{it} = c_i + \phi_1 r_{it-1} + \phi_2 r_{it-2} + \phi_3 r_{it-3} + \phi_4 r_{it-4} + \varepsilon_{it}^{AR}$$

where r_{it} is return of asset *i* in month *t*.

We then corrected this autoregressive estimation by employing the FF3 factor model. We discovered that the data would be best represented by two separate models within the FF3 factor model; one before COVID-19 and one after COVID-19 to determine how volatility responds to the introduction of the vaccine.

The Fama-French 3 Factor Model to estimate asset returns is represented by:

$$r_{it} - r_{ft} = \alpha_i + \beta_1 (r_{mt} - r_{ft}) + \beta_2 SMB_t + \beta_3 HML_t + \varepsilon_t^{FF}$$

where r_{ft} is one-month Treasury bill rate, $r_{mt} - r_{ft}$ is the excess return on the market, SMB_t is Fama-French's Small Minus Big factor, and HML_t is Fama-French's High Minus Low factor in month t.

APARCH (1,1) - Model I, used for volatility estimation, is represented by:

$$\{Var(\varepsilon_t)\}^{\varphi/2} = \sigma_t^{\varphi} = \gamma_0 + \alpha(|\varepsilon_{t-1}| + \gamma_1\varepsilon_{t-1})^{\varphi} + \beta\sigma_{t-1}^{\varphi} + exp(\lambda_0 + \lambda_1Covid_t)$$

APARCH (1,1) - Model II, used for volatility estimation, is represented by:

$$\{Var(\varepsilon_t)\}^{\varphi/2} = \sigma_t^{\varphi} = \gamma_0 + \alpha(|\varepsilon_{t-1}| + \gamma_1\varepsilon_{t-1})^{\varphi} + \beta\sigma_{t-1}^{\varphi} + exp(\lambda_0 + \lambda_1Covid_t + \lambda_2Vaccine_t)$$

where $Covid_t$ takes the value 1 after the end of February 2020 and 0 otherwise and $Vaccine_t$ takes the value 1 after the end of December 2020 and 0 otherwise.

Data

The data selected for this study consist of the daily closing prices of the eleven S&P sector indices, the S&P 500, and eight commodities from the energy, precious metals, industrial metals, and agriculture categories (Gold, Silver, Crude Oil, Natural Gas, Lumber, Wheat, Live Cattle and Aluminum). All data started March 9, 2009, as it marked the market bottom after the 2008 crash (Curto and Serrasqueiro, 2021). This period is congruent with the study we originally replicated as it allowed us to compare our methods. The data ends September 27, 2022 for all series. The S&P 500 data had consistent market close data for every day during the timeframe as the range of total observations ranged from 3417 to 3444 (Table 1). There were discrepancies in the total number of observations for the commodity data as the total values ranged from 2933-3899 (Table 1). This was due to the nature of the commodity market with irregular trading days. To stay comparable with the methods put forth by Curto and Serrasqueiro, two distinct analyses were performed: one until December 31st, 2020, and another until September 27, 2022, to explore the impact of the vaccination programs. The data for the closing S&P 500 were obtained from https://www.investing.com, while the data for the Commodity close were obtained from https://marketinsider.com.

To compute the continuously compounded percentage rates of return, we followed the equation:

$$r_t = 100 \times [\ln(P_t) - \ln(P_{t-1})]$$

In this equation, P_t represents the closing value for each index or commodity at time t.

Table 1 shows summary data for the 11 sectoral indices, the S&P 500, and the eight commodities. Only Consumer Staples and Gold were within one standard deviation, while Financial, Real Estate, Natural Gas, and Wheat were the only positively skewed variables. Crude Oil was our outlier in this analysis as it dropped to a negative closing price in April 2020. This is due to its high kurtosis, standard deviation, and skewness.

TABLE 1 SUMMARY STATISTICS

Commodity	Starting Date	# Obs	Mean	Median	Min	Max	ST. Dev	Skew	Kurt
Gold	3/9/09	3903	0.01	0.00	(8.95)	6.03	0.95	(0.50)	5.31
Silver	3/9/09	3899	0.01	0.00	(14.63)	12.11	1.90	(0.62)	6.53
Crude Oil (WTI)	3/9/09	3429	0.01	0.11	(751.04)	690.88	17.63	(5.00)	1,648.44
Natural Gas	3/9/09	3431	0.02	(0.03)	(30.05)	38.17	3.40	0.50	10.16
Lumber	3/9/09	2933	0.04	0.00	(40.76)	26.77	2.79	(1.42)	28.28
Wheat	3/9/09	3469	0.03	0.00	(16.11)	13.07	1.60	0.06	11.43
Live Cattle	3/9/09	3399	0.02	0.04	(15.65)	8.82	1.17	(1.30)	17.57
Aluminum	3/9/09	3419	0.01	0.00	(7.31)	5.96	1.29	(0.11)	1.83
Index/Stock	Starting Date	# Obs	Mean	Median	Min	Max	ST. Dev	Skew	Kurt
IT	3/9/09	3417	0.07	0.11	(14.98)	11.30	1.38	(0.44)	9.63
НС	3/9/09	3444	0.05	0.07	(10.53)	7.31	1.05	(0.36)	8.22
FI	3/9/09	3416	0.05	0.07	(15.07)	16.33	1.68	0.29	14.91
CD	3/9/09	3416	0.06	0.13	(12.88)	8.29	1.30	(0.59)	7.62
TS	3/9/09	3416	0.02	0.07	(11.03)	8.80	1.20	(0.45)	6.86
ID	3/9/09	3416	0.05	0.08	(12.16)	12.00	1.31	(0.38)	10.09
CS	3/9/09	3416	0.04	0.05	(9.69)	8.07	0.88	(0.47)	14.07
EN	3/9/09	3418	0.02	0.03	(22.42)	15.11	1.77	(0.79)	15.49
UT	3/9/09	3415	0.03	0.09	(12.27)	12.32	1.12	(0.30)	17.48
RE	3/9/09	3415	0.05	0.09	(18.09)	16.24	1.64	0.04	16.92
МТ	3/9/09	3416	0.04	0.08	(12.15)	11.00	1.40	(0.42)	6.60
S&P 500	3/9/09	3414	0.05	0.07	(12.77)	8.97	1.14	(0.62)	12.50

S&P 500 sectors: Information Technology (IT), Health Care (HC), Financials (FI), Consumer Discretionary (CD), Telecom Services (TS), Industrials (ID), Consumer Staples (CS), Energy (EN), Utilities (UT), Real Estate (RE) and Materials (MT).

Table 2 shows the year-end closing price for 2018-2021 of the S&P 500, its sectors, and the eight commodities. It also shows annual growth and incremental change between years. Financials, Energy, Crude Oil, and Live Cattle had negative growth in 2020 while only Gold and Silver had negative growth in 2021. Lumber had the largest growth in 2020 at 115.42%, and it experienced the biggest incremental drop in 2021 at -83.95%. Every sector of the S&P 500 had an incremental drop in 2020 except for the Consumer Discretionary sector, which had an incremental growth of 5.86 percentage points (ppts). Likewise, all the S&P 500 indices fell in 2020 (except for Consumer discretionary), and rose in 2021, (except for Information Technology and Consumer Discretionary). The commodities did not follow this same pattern. All commodities (except for Crude Oil and Live Cattle) had positive incremental change in 2020, and 2021 had an almost equal balance of positive and negative changes.

		Pric	es			Growth		Incremental Change (ppts)		
Index/Commodity	12/31/18	12/31/19	12/31/20	12/31/21	12/31/19	12/31/20	12/31/21	12/31/20	12/31/21	
Gold	1279.45	1517.48	1897.70	1821.50	18.60%	25.06%	-4.02%	6.45	(29.07)	
Silver	15.49	17.86	26.46	23.17	15.25%	48.17%	-12.41%	32.92	(60.58)	
Crude Oil (WTI)	45.41	61.06	48.52	75.21	34.46%	-20.54%	55.01%	(55.00)	75.55	
Natural Gas	2.94	2.19	2.54	3.73	-25.54%	15.99%	46.91%	41.53	30.92	
Lumber	332.50	405.30	873.10	1147.90	21.89%	115.42%	31.47%	93.53	(83.95)	
Wheat	203.25	188.75	213.25	278.50	-7.13%	12.98%	30.60%	20.11	17.62	
Live Cattle	1.25	1.25	1.15	1.40	-0.08%	-7.76%	21.45%	(7.68)	29.21	
Aluminum	1846.00	1810.00	1979.35	2818.45	-1.95%	9.36%	42.39%	11.31	33.04	
IT	1088.30	1611.20	2291.30	3055.40	48.05%	42.21%	33.35%	(5.84)	(8.86)	
HC	1001.18	1188.20	1324.01	1643.92	18.68%	11.43%	24.16%	(7.25)	12.73	
FI	395.90	511.39	490.43	650.04	29.17%	-4.10%	32.54%	(33.27)	36.64	
CD	781.50	986.29	1302.56	1610.76	26.20%	32.07%	23.66%	5.86	(8.41)	
TS	138.78	181.64	221.92	267.48	30.88%	22.18%	20.53%	(8.71)	(1.65)	
ID	542.16	687.60	749.54	894.96	26.83%	9.01%	19.40%	(17.82)	10.39	
CS	521.88	646.97	696.32	804.60	23.97%	7.63%	15.55%	(16.34)	7.92	
EN	424.07	456.46	286.14	422.74	7.64%	-37.31%	47.74%	(44.95)	85.05	
UT	268.61	328.36	319.07	363.71	22.24%	-2.83%	13.99%	(25.07)	16.82	
RE	192.36	240.32	227.90	324.75	24.93%	-5.17%	42.50%	(30.10)	47.66	
МТ	316.62	385.85	455.71	569.63	21.87%	18.11%	25.00%	(3.76)	6.89	
S&P 500	2506.85	3230.78	3756.07	4766.18	28.88%	16.26%	26.89%	(12.62)	10.63	

TABLE 2GROWTH OF INDICES AND COMMODITIES

S&P 500 sectors: Information Technology (IT), Health Care (HC), Financials (FI), Consumer Discretionary (CD), Telecom Services (TS), Industrials (ID), Consumer Staples (CS), Energy (EN), Utilities (UT), Real Estate (RE) and Materials (MT).

Table 3 shows the correlation of all 11 S&P 500 sectors, the S&P 500, and the eight commodities before COVID-19. Table 4 shows the same data, only after December 31st, 2020. We can compare these tables to see if COVID-19 had a change on how these variables were correlated.

TABLE 3 CORRELATION COEFFICIENTS: BEFORE COVID-19

	IT	HC	FI	CD	TS	ID	CS	EN	UT	RE	MT	SP500	Gold	Silver	Oil	Gas	Lumber	Wheat	Cattle	Aluminum
IT	1.000																			
нс	0.724	1.000																		
FI	0.708	0.644	1.000																	
CD	0.857	0.738	0.780	1.000																
TS	0.595	0.562	0.557	0.627	1.000															
ID	0.823	0.733	0.821	0.873	0.616	1.000														
CS	0.641	0.706	0.592	0.696	0.623	0.690	1.000													
EN	0.672	0.615	0.679	0.697	0.530	0.768	0.566	1.000												
UT	0.430	0.486	0.422	0.474	0.483	0.498	0.656	0.444	1.000											
RE	0.577	0.513	0.772	0.682	0.494	0.672	0.580	0.531	0.565	1.000										
MT	0.769	0.679	0.767	0.800	0.562	0.873	0.632	0.793	0.465	0.626	1.000									
SP500	0.910	0.835	0.870	0.926	0.684	0.936	0.773	0.810	0.562	0.718	0.881	1.000								
Gold	-0.010	-0.013	-0.026	-0.031	0.012	0.002	0.031	0.095	0.115	0.073	0.140	0.013	1.000							
Silver	0.141	0.117	0.128	0.122	0.090	0.165	0.137	0.257	0.156	0.162	0.294	0.182	0.748	1.000						
Oil	0.315	0.248	0.332	0.327	0.238	0.383	0.243	0.637	0.194	0.274	0.431	0.397	0.149	0.271	1.000					
Gas	0.013	0.024	0.035	0.043	0.043	0.051	0.040	0.146	0.056	0.040	0.068	0.054	0.007	0.055	0.136	1.000				
Lumber	0.095	0.067	0.091	0.092	0.046	0.109	0.047	0.091	0.041	0.074	0.107	0.100	0.027	0.046	0.084	0.005	1.000			
Wheat	0.046	0.040	0.045	0.041	0.042	0.055	0.032	0.056	0.024	0.030	0.063	0.054	0.023	0.058	0.037	0.031	0.004	1.000		
Cattle	0.117	0.092	0.104	0.115	0.091	0.124	0.098	0.100	0.051	0.088	0.114	0.122	0.043	0.068	0.106	0.014	0.018	0.031	1.000	
Aluminum	0.204	0.132	0 217	0.210	0.103	0.246	0.115	0.245	0.104	0.172	0.280	0 231	0.151	0 244	0.233	0.076	0.051	0.004	0.031	1 000

S&P 500 sectors: Information Technology (IT), Health Care (HC), Financials (FI), Consumer Discretionary (CD), Telecom Services (TS), Industrials (ID), Consumer Staples (CS), Energy (EN), Utilities (UT), Real Estate (RE) and Materials (MT). We used Stata Data Package to produce correlations. Stronger correlations are represented in darker green shades while weaker correlations are represented in darker red shades.

 TABLE 4

 CORRELATION COEFFICIENTS: AFTER COVID-19

	IT	HC	FI	CD	TS	ID	CS	FN	UT	RF	MT	SP500	Gold	Silver	Oil	Gas	Lumber	Wheat	Cattle	Aluminum
IT	1.000																			
нс	0.842	1.000																		
FI	0.729	0.775	1.000																	
CD	0.921	0.794	0.752	1.000																
TS	0.908	0.800	0.731	0.890	1.000															
ID	0.761	0.812	0.939	0.795	0.744	1.000														
CS	0.791	0.863	0.755	0.752	0.783	0.793	1.000													
EN	0.578	0.614	0.840	0.607	0.593	0.815	0.564	1.000												
UT	0.694	0.807	0.743	0.683	0.675	0.773	0.858	0.539	1.000											
RE	0.780	0.826	0.837	0.789	0.748	0.856	0.819	0.657	0.861	1.000										
MT	0.775	0.815	0.906	0.799	0.750	0.934	0.788	0.793	0.770	0.833	1.000									
SP500	0.948	0.914	0.885	0.929	0.915	0.907	0.876	0.731	0.811	0.886	0.902	1.000								
Gold	0.234	0.161	0.040	0.241	0.192	0.096	0.187	0.057	0.169	0.157	0.201	0.188	1.000							
Silver	0.286	0.221	0.183	0.322	0.291	0.223	0.197	0.205	0.184	0.245	0.294	0.277	0.701	1.000						
Oil	0.151	0.123	0.134	0.131	0.137	0.156	0.140	0.183	0.128	0.147	0.157	0.157	0.000	0.046	1.000					
Gas	0.127	0.120	0.114	0.124	0.106	0.109	0.083	0.093	0.079	0.111	0.105	0.125	0.008	0.051	-0.056	1.000				
Lumber	0.254	0.220	0.246	0.255	0.245	0.241	0.218	0.197	0.166	0.201	0.262	0.263	0.087	0.131	0.101	0.078	1.000			
Wheat	0.093	0.060	0.094	0.115	0.065	0.077	0.022	0.098	0.033	0.069	0.085	0.090	-0.010	0.018	-0.069	0.041	-0.007	1.000		_
Cattle	0.114	0.092	0.173	0.202	0.134	0.176	0.052	0.171	0.142	0.182	0.190	0.152	-0.012	0.104	0.084	0.007	0.022	0.065	1.000)
Aluminum	0.121	0.158	0.183	0.133	0.106	0.203	0.198	0.165	0.126	0.170	0.210	0.165	0.087	0.120	0.067	0.102	0.125	-0.025	-0.017	1.000

S&P 500 sectors: Information Technology (IT), Health Care (HC), Financials (FI), Consumer Discretionary (CD), Telecom Services (TS), Industrials (ID), Consumer Staples (CS), Energy (EN), Utilities (UT), Real Estate (RE) and Materials (MT). We used Stata Data Package to produce correlations. Stronger correlations are represented in darker green shades while weaker correlations are represented in darker red shades.

When reviewing both Table 3 and Table 4, we note that the S&P 500 sectors are most strongly correlated to each other, the commodities have weaker correlations with each other, and the S&P 500 indices have the weakest correlation with the commodities. When comparing the two tables, both the S&P 500 sectors' correlation with each other, as well as the commodities correlation with each other, strengthened. However, the correlation between the S&P 500 sectors and commodities weakened.

One interesting result from comparing these tables is that before COVID-19, Crude Oil and the Energy sector had a strong, positive correlation of 0.637. After COVID-19, however, this correlation fell considerably to 0.183.

Empirical Results

Curto and Serrasqueiro (2021) combined Model I (before COVID-19) and Model II (after COVID-19). Their goal was to find the error term. They assumed, by combining the data, that the variables have the same assumptions, which they do not. Model II follows a different assumption with different parameters to account for the vaccine's effect on volatility. To correct this, we divided the data and made separate analyses, as shown in Table 1 and Table 2 in the Appendix.

The APARCH (1,1) AR (4) model, when split into two separate charts to accommodate for different parameters before and after COVID-19, did not find a statistically significant difference in volatility between the sectors and commodities because of COVID-19. To follow the APARCH (1,1) AR (4) model, the ϕ_1, ϕ_2, ϕ_3 and ϕ_4 (represented by L1, L2, L3, and L4) is shown as well as its statistical significance in Appendix Table 1. Only 16% of these L1-L4 values fell within 1% significance, 20% fell within 5% significance, and 25% fell within 10% significance. Appendix Table 2 is very similar as only 18% of the L1-L4 values fell within 1% significance, and 28% within 10% significance. These values are too low to empirically prove that there was a statistically significant difference in volatility between the sectors and commodities.

We next employed the Fama-French 3-Factor Model and the results are shown in Tables 5 and 6. Volatility clustering is shown in both tables with the α and β columns. We see both high and low volatility that are statistically significant (except for Wheat). The $\alpha + \beta$ on both tables are statistically significant, ranging from 0.742 to 1.000, with most falling in the 0.900 to 0.999 range, which shows that shocks on volatility cluster and cancel out over time.

The statistical significance problem presented in the APARCH (1,1) AR (4) Model for asset returns is resolved as 83% of the β 1- β 3 values fell within 1% significance, and 89% fell within 5% significance.

 TABLE 5

 ESTIMATION RESULTS OF MODEL 1: APARCH (1,1) WITH FAMA-FRENCH 3 FACTOR

Index/Commodity	a	β	a+β	power (δ)	leverage (γ)	Covid(λ 1:Model I)	β1	β2	β3
Gold	0.063 ***	0.919 ***	0.982	1.848 ***	0.040	0.279	0.023	0.047	-0.068 ***
(z-score)	(8.30)	(139.65)		(10.03)	(1.04)	(1.33)	(1.60)	(1.54)	(3.21)
Silver	0.051 ***	0.899 ***	0.950	2.737 ***	0.058 *	0.934 ***	0.292 ***	0.194 ***	0.047
(z-score)	(5.26)	(113.78)		(8.58)	(1.81)	(2.66)	(11.63)	(3.88)	(1.00)
Crude Oil (WTI)	0.714 ***	0.242 ***	0.956	4.239 ***	-0.433 ***	1.290 ***	0.718 ***	0.207 ***	0.748 ***
(z-score)	(11.81)	(7.09)		(8.18)	(15.22)	(3.51)	(29.58)	(4.46)	(16.99)
Natural Gas	0.090 ***	0.906 ***	0.996	1.711 ***	-0.020	1.450 ***	0.128 ***	-0.049	0.218 ***
(z-score)	(11.48)	(143.99)		(9.82)	(0.64)	(5.89)	(2.58)	(0.54)	(2.86)
Lumber	0.029 ***	0.923 ***	0.952	-0.277 ***	0.547 ***	-0.145 ***	0.068 ***	-0.017 ***	-0.088 ***
(z-score)	(18.74)	(278.44)		(13.49)	(13.78)	(6.05)	(732.28)	(704.23)	(742.49)
Wheat	25.250	0.044	25.294	10.398 ***	0.339 ***	-0.786	0.021 **	0.259 ***	-0.070 ***
(z-score)	(1.26)	(1.43)		(4.12)	(22.00)	(0.83)	(1.97)	(7.81)	(3.05)
Live Cattle	0.081 ***	0.791 ***	0.872	-0.025	0.238 ***	-0.012	0.024 ***	0.108 ***	0.176 ***
(z-score)	(11.46)	(72.97)		(0.51)	(4.54)	(0.51)	(126.36)	(530.38)	(831.72)
Aluminum	0.036 ***	0.949 ***	0.985	2.123 ***	0.067	-0.211	0.163 ***	0.060 **	0.112 ***
(z-score)	(4.00)	(123.10)		(5.06)	(1.20)	(0.64)	(9.89)	(1.81)	(4.58)
IT	0.194 ***	0.550 ***	0.744	1.284 ***	-0.004	0.294 ***	1.160 ***	-0.151 ***	-0.374 ***
(z-score)	(10.92)	(11.63)		(5.84)	(0.08)	(3.20)	(205.85)	(12.34)	(42.37)
HC	0.064 ***	0.888 ***	0.952	2.172 ***	-0.167 ***	1.378 ***	0.872 ***	-0.181 ***	-0.296 ***
(z-score)	(5.40)	(76.67)		(7.09)	(2.97)	(3.85)	(109.30)	(12.53)	(24.38)
FI	0.061 ***	0.918 ***	0.979	2.194 ***	0.046	1.432 ***	1.127 ***	-0.085 ***	0.797 ***
(z-score)	(7.23)	(130.28)		(9.07)	(1.22)	(5.28)	(199.22)	(7.48)	(84.11)
CD	0.018 ***	0.940 ***	0.958	3.374 ***	0.154 ***	1.728 ***	1.012 ***	-0.016	-0.166 ***
(z-score)	(3.50)	(125.17)		(8.83)	(3.03)	(3.87)	(141.46)	(1.31)	(15.37)
TS	0.049 ***	0.945 ***	0.994	1.346 ***	0.111 **	0.265 **	0.783 ***	-0.272 ***	-0.087 ***
(z-score)	(10.04)	(192.18)		(7.11)	(2.01)	(1.98)	(72.78)	(13.48)	(4.70)
ID	0.061 ***	0.923 ***	0.984	1.474 ***	-1.014	1.122 ***	1.031 ***	0.028 **	0.200 ***
(z-score)	(8.58)	(98.15)		(5.46)	(1.53)	(3.93)	(165.97)	(2.32)	(17.75)
CS	0.089 ***	0.883 ***	0.972	1.617 ***	-0.980 *	0.510 **	0.645 ***	-0.298 ***	-0.113 ***
(z-score)	(8.31)	(67.12)		(7.67)	(1.85)	(2.51)	(86.37)	(21.05)	(9.51)
EN	0.072 ***	0.928 ***	1.000	1.051 ***	-0.432 ***	1.051 ***	1.066 ***	-0.094 ***	0.450 ***
(z-score)	(12.36)	(158.93)		(7.07)	(6.31)	(4.50)	(83.28)	(3.99)	(20.68)
UT	0.069 ***	0.924 ***	0.993	1.931 ***	0.054	0.519	0.565 ***	-0.286 ***	0.028
(z-score)	(8.00)	(133.87)		(7.11)	(1.31)	(0.78)	(49.61)	(12.35)	(1.41)
RE	0.067 ***	0.913 ***	0.980	2.159 ***	0.022	0.870 ***	0.844 ***	-0.065 **	0.121 ***
(z-score)	(7.55)	(111.13)		(8.75)	(0.59)	(3.18)	(64.13)	(2.49)	(5.45)
MT	0.039 ***	0.949 ***	0.988	1.871 ***	-0.086	1.046 ***	1.053 ***	0.045 ***	0.252 ***
(z-score)	(6.07)	(145.40)		(7.43)	(1.33)	(3.97)	(114.72)	(2.79)	(17.04)

S&P 500 sectors: Information Technology (IT), Health Care (HC), Financials (FI), Consumer Discretionary (CD), Telecom Services (TS), Industrials (ID), Consumer Staples (CS), Energy (EN), Utilities (UT), Real Estate (RE) and Materials (MT). $\alpha + \beta = 1$ is the measure of volatility persistence. θ 1 represents the effect of COVID-19 until December 31st, 2020. β 1 represents the values when placed in the model equation to find the error term.

*Denote statistically significant 10%

**Denote statistically significant at the 5%.

***Denote statistically significant at the 1%.

The statistical significance problem presented in the APARCH (1,1) AR (4) Model for asset returns is also resolved as 84% of the β 1- β 3 values fell within 1% significance, and 91% fell within 5% significance. Table 5 and Table 6 show our key variables, Covid (λ 1: Model I), Covid (λ 1: Model II), and Vaccine (λ 2), along with their statistical significance. Positive values represent an increase in volatility and negative values represent a decrease in volatility. We see that the S&P 500 sectors all had a positive volatility reaction to both COVID-19 periods, and a negative response(except for Consumer Staples) to the vaccine programs. COVID-19 caused an increase in volatility in the financial market, and the introduction of the vaccine programs caused the volatility to drop.

 TABLE 6

 ESTIMATION RESULTS OF MODEL 2: APARCH (1,1) WITH FAMA-FRENCH 3 FACTOR

Index/Commodity	а	β	a+β	power (δ)	leverage (γ)	Covid(λ1:Model II)	Vaccine(λ2)	β1	β2	β3
Gold	0.058 ***	0.92 ***	0.982	1.880 ***	0.040	0.434 **	-0.966	0.028 **	0.062 **	-0.072 ***
(z-score)	(8.06)	(149.97)		(10.03)	(1.03)	(2.24)	(1.37)	(2.00)	(2.15)	(3.58)
Silver	0.054 ***	0.895 ***	0.949	2.650 ***	0.064 **	1.047 ***	-0.391	0.291 ***	0.212 ***	0.056
(z-score)	(5.50)	(109.55)		(8.52)	(1.99)	(3.28)	(0.63)	(11.66)	(4.37)	(1.23)
Crude Oil (WTI)	0.079 ***	0.913 ***	0.992	0.140 ***	-0.636 ***	* 0.704 ***	-0.608 ***	0.713 ***	0.092 ***	0.550 ***
(z-score)	(13.70)	(183.94)		(2.92)	(15.12)	(2.93)	(2.87)	(245.36)	(12.91)	(356.28)
Natural Gas	0.088 ***	0.907 ***	0.995	1.723 ***	-0.018	1.407 ***	-1.956 ***	0.127 ***	-0.016	0.205 ***
(z-score)	11.39	145.77		(9.93)	(0.57)	(5.91)	(3.33)	(2.61)	(0.18)	(2.84)
Lumber	0.154 ***	0.644 ***	0.798	0.064 **	0.099 ***	* 0.041 **	0.012	0.114 ***	-0.097 ***	0.070 ***
(z-score)	(18.39)	(76.29)		(2.05)	(3.51)	(2.09)	(1.51)	(71.17)	(70.18)	(72.96)
Wheat	21.960	0.045	22.005	10.344 ***	0.351 ***	* -0.920	4.017 *	0.023 **	0.261 ***	-0.081 ***
(z-score)	(1.38)	(1.51)		(4.32)	(23.99)	(0.99)	(1.89)	(2.24)	(8.12)	(3.58)
Live Cattle	0.084 ***	0.784 ***	0.868	0.032	0.310 ***	* 0.018	-0.030	0.078 ***	0.048 ***	0.125 ***
(z-score)	(11.33)	(66.03)		(0.60)	(6.02)	(0.60)	(0.60)	(2,411.43)	(61.39)	(600.77)
Aluminum	0.038 ***	0.947 ***	0.985	2.056 ***	0.073	-0.218	0.529	0.161 ***	0.056 *	0.120 ***
(z-score)	(4.18)	(118.80)		(5.06)	(1.31)	(0.71)	(0.82)	(9.86)	(1.74)	(5.05)
IT	0.186 ***	0.556 ***	0.742	1.393 ***	0.007	0.321 ***	-0.038	1.161 ***	-0.151 ***	-0.374 ***
(z-score)	(10.62)	(11.55)		(5.97)	(0.16)	(3.29)	(0.29)	(207.69)	(12.84)	(44.35)
HC	0.060 ***	0.891 ***	0.951	2.228 ***	-0.163 ***	* 1.465 ***	-0.094	0.862 ***	-0.180 ***	-0.264 ***
(z-score)	(5.12)	(77.58)		(6.96)	(2.87)	(4.26)	(0.21)	(108.42)	(12.67)	(22.18)
FI	0.061 ***	0.917 ***	0.978	2.175 ***	0.037	1.475 ***	-1.981 **	1.127 ***	-0.095 ***	0.790 ***
(z-score)	(7.34)	(131.25)		(9.30)	(1.01)	(5.72)	(1.93)	(205.22)	(8.61)	(88.43)
CD	0.019 ***	0.941 ***	0.960	3.281 ***	0.138 ***	* 1.781 ***	-0.908	1.014 ***	-0.015	-0.171 ***
(z-score)	(3.57)	(127.57)		(8.62)	(2.76)	(4.31)	(0.78)	(144.93)	(1.22)	(16.77)
TS	0.046 ***	0.948 ***	0.994	1.327 ***	0.093	0.290 **	-0.447	0.791 ***	-0.274 ***	-0.098 ***
(z-score)	(9.93)	(198.52)		(6.79)	(1.64)	(2.20)	(1.22)	(75.49)	(14.08)	(5.54)
ID	0.062 ***	0.920 ***	0.982	1.510 ***	-0.086	1.12 ***	-0.579	1.026 ***	0.025 **	0.225 ***
(z-score)	(8.58)	(93.26)		(5.39)	(1.33)	(4.05)	(1.49)	(166.62)	(2.11)	(20.65)
CS	0.084 ***	0.887 ***	0.971	1.646 ***	-1.000 *	0.487 **	0.119	0.637 ***	-0.297 ***	-0.087 ***
(z-score)	(8.07)	(69.86)		(7.58)	(1.90)	(2.44)	(0.29)	(86.34)	(21.46)	(7.50)
EN	0.069 ***	0.930 ***	0.999	1.087 ***	-0.428 ***	* 1.107 ***	-0.117	1.060 ***	-0.081 ***	0.48 ***
(z-score)	(12.12)	(163.46)		(6.99)	(6.22)	(4.63)	(0.30)	(83.79)	(3.45)	(22.66)
UT	0.067 ***	0.924 ***	0.991	1.953 ***	0.042	0.892 *	(0.78)	0.566 ***	-0.294 ***	0.025
(z-score)	(7.80)	(132.71)		(7.08)	(1.02)	(1.88)	(0.67)	(50.54)	(13.16)	(1.36)
RE	0.067 ***	0.911 ***	0.978	2.164 ***	0.012	1.038 ***	-1.286 *	0.835 ***	-0.093 ***	0.104 ***
(z-score)	(7.58)	(110.24)		(8.91)	(0.33)	(3.94)	(1.71)	(64.58)	(3.71)	(4.98)
MT	0.036 ***	0.952 ***	0.988	1.940 ***	-0.087	1.121 ***	-0.892	1.048 ***	0.044 ***	0.275 ***
(z-score)	(5.76)	(154.01)		(7.59)	(1.38)	(4.26)	(1.34)	(115.42)	(2.86)	(19.38)

S&P 500 sectors: Information Technology (IT), Health Care (HC), Financials (FI), Consumer Discretionary (CD), Telecom Services (TS), Industrials (ID), Consumer Staples (CS), Energy (EN), Utilities (UT), Real Estate (RE) and Materials (MT). $\alpha + \beta = 1$ is the measure of volatility persistence. Covid ($\lambda 1$: Model I) represents the effect of COVID-19 until December 31st, 2020, and Covid ($\lambda 1$: Model II) represents the effect of COVID-19 until September 27th, 2022. Vaccine($\lambda 2$) covers the period from January through September 27th, 2022, to measure the impact of vaccination programs on volatility. $\beta 1$ represents the values when placed in the model equation to find the error term. *Denote statistically significant 10%

**Denote statistically significant at the 5%.

***Denote statistically significant at the 1%.

The commodities that we analyzed do not react the same way. The precious metals (Gold and Silver) and energy (Crude Oil and Natural Gas) react in a similar manner to the financial markets: an increase in volatility caused by COVID-19, and a decrease in volatility with the introduction of the vaccine. The agricultural (Lumber, Wheat, and Live Cattle) and industrial metals (Aluminum) markets, follow a different trend. These markets, with the exception of Live Cattle, show a decrease in volatility during the COVID-19 period, and an increase or no change in volatility. Live Cattle shows no significant changes to either period.

Findings

The Impact of COVID-19 on Return Volatility Is Different Between Commodities and Financial Markets

Out of 8 commodities we study, the return volatility of about half of commodities (lumber, wheat, live cattle, and aluminum) either decreases or does not change during the COVID-19 pandemic period. The lumber return shows a statistically significant drop in volatility during the pandemic period. The return

volatility of all S&P 500 sectors increases during the COVID-19 pandemic period. Though the size of impact varies across different sectors, the direction of impact is the same.

Unlike S&P500 Sectors, Commodity Return Volatility Is Less Sensitive to the Impact of COVID-19

The return volatility of wheat, live cattle, and aluminum is not affected by the COVID-19. The vaccination program does not have any impact on these commodities either. After the introduction of vaccination programs, the return volatility of S&P 500 sectors decreases, but the impact is not statistically significant, except in the Financial Sector.

The Impact of Vaccination Programs on Return Volatility Is Weak

Not all commodity return volatilities decrease after the vaccination programs. Though not statistically significant, the return volatility of three commodities (lumber, wheat, and aluminum) increases even after the introduction of vaccination programs. Only one S&P 500 sector, Financials, shows a statistically significant decrease in return volatility due to the vaccination programs, though all S&P 500 sectors show a decrease in volatility after the programs.

CONCLUSIONS

Although the COVID-19 pandemic was a major negative shock to the US economy in 2020, it did not impact financial markets and commodities in the same way. Volatility was found to be less sensitive in commodity returns than in the returns of the S&P 500 sectors. The effect of vaccination also did not impact financial markets and commodities in the same way.

All S&P 500 sectors show a decrease in return volatility with the introduction of vaccination programs, whereas commodities in the agriculture and industrial metal markets showed increases in return volatility during the same period.

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APPENDIX

Index/Commodity	a	β	a+β	power (δ)	leverage (γ)	covid (θ 1)	L1	L2	L3	L4
Gold	0.064 ***	0.917 ***	0.981	1.835 ***	0.037	0.356 *	-0.035 *	0.010	(0.015)	0.005
(z-score)	(8.30)	(135.68)		(10.09)	(0.92)	(1.91)	(1.68)	(0.53)	(0.82)	(0.27)
Silver	0.055 ***	0.902 ***	0.957	2.578 ***	0.053	0.882 ***	-0.028	0.010	-0.009	-0.030
(z-score)	(5.88)	(131.20)		(9.01)	(1.63)	(2.74)	(1.40)	(0.49)	(0.50)	(1.53)
Crude Oil (WTI)	0.057 ***	0.929 ***	0.986	0.061	-0.857 ***	0.241	-0.009	0.040 ***	-0.045 ***	0.027 ***
(z-score)	(12.77)	(195.13)		(1.45)	(35.57)	(1.44)	-	(101.19)	(223.36)	(44.86)
Natural Gas	0.089 **	0.907 ***	0.996	1.747 ***	-0.017	1.455 ***	-0.036 *	-0.017	-0.020	-0.008
(z-score)	(10.89)	(142.06)		(10.09)	(0.55)	(5.78)	(1.77)	(0.87)	(1.04)	(0.42)
Lumber	0.108 ***	0.823 ***	0.931	0.461 ***	-0.046	0.263 ***	0.082 ***	-0.081 ***	-0.029 ***	-0.042 ***
(z-score)	(8.82)	(59.61)		(4.17)	(1.25)	(3.76)	(4.95)	(5.06)	(2.92)	(2.91)
Wheat	7.21 ***	0.149 ***	7.359	6.015 ***	0.323 ***	-0.842	-0.092 ***	-0.048 ***	0.054 ***	0.197 ***
(z-score)	(3.46)	(4.21)		(7.73)	(15.88)	(1.64)	(4.45)	(3.11)	(3.25)	(17.34)
Live Cattle	0.113 ***	0.797 ***	0.910	0.557 ***	0.190 ***	0.393 ***	0.029 **	0.001	0.008	0.019
(z-score)	(12.54)	(55.01)		(6.31)	(3.96)	(8.81)	(1.92)	(0.04)	(1.16)	(1.37)
Aluminum	0.025 ***	0.955 ***	0.980	2.686 ***	0.023	-0.131	0.004	0.016	-0.010	0.001
(z-score)	(3.15)	(145.97)		(5.61)	(0.54)	(0.30)	(0.20)	(0.82)	(0.57)	(0.03)
IT	0.120 ***	0.844 ***	0.964	1.045 ***	-0.793 ***	0.770 ***	-0.023	0.009	0.001	0.011
(z-score)	(11.91)	(70.33)		(9.17)	(10.36)	(8.47)	(1.23)	(0.50)	(0.05)	(0.64)
HC	0.100 ***	0.870 ***	0.970	1.106 ***	-0.763 ***	0.329 ***	-0.023	-0.003	0.004	-0.032 *
(z-score)	(11.29)	(84.47)		(8.57)	(9.71)	(2.96)	(1.20)	(0.19)	(0.24)	(1.69)
FI	0.135 ***	0.835 ***	0.970	1.819 ***	-0.274 ***	0.619 *	-0.045 **	0.031 *	-0.019	-0.006
(z-score)	(11.89)	(86.78)		(10.33)	(8.55)	(1.92)	(2.33)	(1.69)	(0.99)	(0.32)
CD	0.113 ***	0.853 ***	0.966	1.615 ***	-0.422 ***	0.899 ***	-0.012	-0.008	-0.027	0.006
(z-score)	(10.30)	(76.47)		(9.68)	(7.99)	(5.73)	(0.59)	(0.43)	(1.41)	(0.36)
TS	0.084 ***	0.854 ***	0.938	1.873 ***	-0.222 ***	0.801 ***	0.002	-0.223	-0.031	0.018
(z-score)	(7.11)	(56.24)		(7.25)	(5.24)	(5.15)	(0.10)	(1.18)	(1.56)	(1.00)
ID	0.102 ***	0.868 ***	0.970	1.665 ***	-0.481 ***	0.605 **	0.011	0.014	0.000	-0.018
(z-score)	(8.97)	(95.50)		(9.06)	(8.54)	(2.21)	(0.57)	(0.72)	(0.01)	(0.93)
CS	0.121 ***	0.841 ***	0.962	1.277 ***	-0.530 ***	0.475 ***	-0.052 ***	-0.006	-0.013	-0.029
(z-score)	(10.49)	(62.37)		(7.66)	(7.28)	(3.70)	(2.61)	(0.33)	(0.72)	(1.59)
EN	0.093 ***	0.898 ***	0.991	1.002 ***	-0.581 ***	0.940 ***	-0.020	0.020	-0.011	0.011
(z-score)	(11.80)	(109.04)		(8.14)	(7.79)	(5.95)	(1.07)	(1.00)	(0.56)	(0.60)
UT	0.066 ***	0.885 ***	0.951	2.555 ***	-0.105 **	0.930 ***	-0.017	-0.027	-0.028	-0.027
(z-score)	(5.46)	(78.35)		(7.83)	(2.22)	(2.56)	(0.84)	(1.36)	(1.41)	(1.35)
RE	0.116 ***	0.854 ***	0.970	2.204 ***	-0.138 ***	0.585	-0.035 **	0.010	0.000	-0.030
(z-score)	(9.45)	(78.55)		(8.12)	(3.57)	(0.80)	(1.83)	(0.49)	0.00	(1.58)
MT	0.104 ***	0.891 ***	0.995	1.134 ***	-0.540 ***	0.540 ***	-0.017	0.018	-0.011	-0.026
(z-score)	(11.44)	(93.78)		(8.18)	(9.02)	(3.54)	(0.94)	(0.98)	(0.59)	(1.39)
S&P 500	0.144 ***	0.849 ***	0.993	0.850 ***	-0.729 ***	0.552 ***	-0.057 ***	0.008	-0.014	0.008
(z-score)	(17.10)	(94.48)		(11.25)	(15.73)	(6.64)	(3.23)	(0.54)	(0.84)	(0.49)

TABLE 1 APARCH (1,1), AR (4) MODEL 1 ESTIMATION RESULTS

S&P 500 sectors: Information Technology (IT), Health Care (HC), Financials (FI), Consumer Discretionary (CD), Telecom Services (TS), Industrials (ID), Consumer Staples (CS), Energy (EN), Utilities (UT), Real Estate (RE) and Materials (MT). $\alpha + \beta = 1$ is the measure of volatility persistence. θ represents the effect of COVID-19 until December 31st, 2020. L1-L4 represents the values when placed in the model equation to find the error term. *Denote statistically significant 10%

**Denote statistically significant at the 5%.

***Denote statistically significant at the 1%.

TABLE 2APARCH (1,1), AR (4) MODEL 2 ESTIMATION RESULTS

Index/Commodity	a	β	a+β	power (δ)	leverage (γ)	covid ($ heta$ 2)	vaccine (ϕ)	L1	L2	L3	L4
Gold	0.060 ***	0.922 ***	0.982	1.870 ***	0.031	0.508 ***	-0.974	-0.031	-0.009	-0.015	-0.004
(z-score)	(8.11)	(146.65)		(10.16)	(0.80)	(2.87)	(1.34)	(1.49)	(0.46)	(0.80)	(0.19)
Silver	0.057 ***	0.900 ***	0.957	2.507 ***	0.057 *	0.993 ***	-0.316	-0.032 *	0.001	-0.009	-0.032 *
(z-score)	(6.06)	(127.56)		(8.90)	(1.77)	(3.40)	(0.45)	(1.66)	(0.06)	(0.52)	(1.66)
Crude Oil (WTI)	0.060 ***	0.925 ***	0.985	0.038	-0.778 ***	0.175	-0.166	-0.036 ***	0.087 ***	-0.122 ***	-0.026 ***
(z-score)	(13.01)	(205.62)		(0.98)	(24.92)	(0.97)	(0.98)	(26.37)	(92.46)	(173.32)	(13.89)
Natural Gas	0.086 ***	0.908 ***	0.994	1.761 ***	-0.016	1.416 ***	-1.823 ***	-0.037 *	-0.018	-0.015	-0.008
(z-score)	(10.82)	(143.01)		(10.18)	(0.50)	(5.82)	(3.71)	(1.84)	(0.98)	(0.78)	(0.45)
Lumber	0.100 ***	0.837 ***	0.937	0.451 ***	-0.068 ***	0.265 ***	0.212 ***	0.075 ***	-0.062 ***	-0.022 *	-0.042 ***
(z-score)	(9.46)	(72.61)		(4.61)	(1.91)	(4.22)	(4.03)	(5.63)	(4.98)	(1.74)	(3.82)
Wheat	0.345 ***	0.454 ***	0.799	0.137 ***	-0.400 ***	-0.163 ***	0.072 **	0.149 ***	0.208 ***	0.028 ***	0.075 ***
(z-score)	(14.56)	(28.18)		(4.28)	(12.50)	(3.55)	(2.41)	(197.57)	(169.98)	(22.11)	(41.19)
Live Cattle	0.111 ***	0.794 ***	0.905	0.528 ***	0.208 ***	0.369 ***	-0.527 ***	0.029 ***	0.001	0.008	0.015
(z-score)	(12.53)	(56.71)		(6.09)	(4.38)	(8.27)	(5.80)	(3.37)	(0.09)	(0.63)	(1.48)
Aluminum	0.026 ***	0.955 ***	0.981	2.636 ***	0.028	-0.169	0.870	0.002	0.011	-0.012	0.002
(z-score)	(3.24)	(143.91)		(5.60)	(0.65)	(0.39)	(1.12)	(0.09)	(0.60)	(0.65)	(0.10)
IT	0.118 ***	0.845 ***	0.963	1.048 ***	-0.760 ***	0.778 ***	-0.587 **	-0.03	0.007	0.002	0.017
(z-score)	(11.93)	(71.45)		(9.28)	(10.63)	(8.57)	(2.61)	(1.60)	(0.39)	(0.11)	(1.02)
HC	0.099 ***	0.871 ***	0.970	1.065 ***	-0.775 ***	0.336 ***	-0.273 **	-0.025	-0.007	0.005	-0.024
(z-score)	(11.74)	(85.38)		(8.72)	(10.11)	(3.17)	(1.93)	(1.29)	(0.44)	(0.25)	(1.30)
FI	0.132 ***	0.835 ***	0.967	1.857 ***	-0.281 ***	0.914 ***	-0.575	-0.043 **	0.028	-0.019	-0.007
(z-score)	(11.69)	(86.24)		(10.60)	(8.86)	(3.66)	(1.10)	(2.27)	(1.55)	(1.02)	(0.34)
CD	0.111 ***	0.853 ***	0.964	1.637 ***	-0.424 ***	0.948 ***	-0.162	-0.013	-0.007	-0.025	0.008
(z-score)	(10.16)	(76.26)		(9.69)	(8.04)	(5.98)	(0.59)	(0.67)	(0.42)	(1.35)	(0.44)
TS	0.082 ***	0.853 ***	0.935	1.890 ***	-0.221 ***	0.818 ***	-0.230	0.002	-0.026	-0.033 *	0.025
(z-score)	(7.00)	(55.69)		(7.25)	(5.25)	(5.23)	(0.93)	(0.10)	(1.35)	(1.70)	(1.35)
ID	0.101 ***	0.866 ***	0.967	1.677 ***	-0.485 ***	0.754 ***	0.473	0.007	0.009	0.000	-0.015
(z-score)	(8.96)	(94.87)		(9.19)	(8.71)	(3.11)	(1.20)	(0.35)	(0.47)	(0.01)	(0.80)
CS	0.121 ***	0.841 ***	0.962	1.259 ***	-0.522 ***	0.459 ***	-0.241	-0.051 ***	-0.010	-0.015	-0.030 **
(z-score)	(10.71)	(62.18)		(7.68)	(7.32)	(3.67)	(1.06)	(2.59)	(0.56)	(0.79)	(1.69)
EN	0.091 ***	0.901 ***	0.992	1.023 ***	-0.570 ***	1.000 ***	-0.373	-0.020	0.022	-0.010	0.009
(z-score)	(11.58)	(111.03)		(8.19)	(7.53)	(6.06)	(1.17)	(1.07)	(1.17)	(0.53)	0.46
UT	0.066 ***	0.884 ***	0.950	2.557 ***	-0.109 **	1.092 ***	-0.664	-0.017	-0.032 *	-0.025	-0.026
(z-score)	(5.45)	(77.13)		(7.85)	(2.32)	(3.19)	(0.98)	(0.89)	(1.66)	(1.32)	(1.30)
RE	0.116 ***	0.859 ***	0.975	2.098 ***	-0.156 ***	0.804 *	-0.567	-0.032 *	0.009	-0.001	-0.026
(z-score)	(9.98)	(81.90)		(8.21)	(3.91)	(1.65)	(0.85)	(1.71)	(0.46)	(0.06)	(1.41)
MT	0.101 ***	0.893 ***	0.994	1.119 ***	-0.552 ***	0.632 ***	-0.329	-0.015	0.014	-0.014	-0.022
(z-score)	(11.56)	(95.39)		(8.16)	(9.26)	(4.24)	(1.16)	(0.84)	(0.75)	(0.77)	(1.17)
S&P 500	0.142 ***	0.850 ***	0.992	0.840 ***	-0.751 ***	0.565 ***	-0.366	-0.059 ***	0.008	-0.013	0.015
(z-score)	(17.45)	(96.35)		(11.30)	(16.62)	(6.96)	(2.83) ***	(3.43)	(0.48)	(0.80)	(0.98)

S&P 500 sectors: Information Technology (IT), Health Care (HC), Financials (FI), Consumer Discretionary (CD), Telecom Services (TS), Industrials (ID), Consumer Staples (CS), Energy (EN), Utilities (UT), Real Estate (RE) and Materials (MT). $\alpha + \beta = 1$ is the measure of volatility persistence. θ I represents the effect of COVID-19 until December 31st, 2020, and θ 2 represents the effect of COVID-19 until September 27th, 2022. ϕ covers the period from January through September 27th, 2022, to measure the impact of vaccination programs on volatility. L1-L4 represents the values when placed in the model equation to find the error term.

*Denote statistically significant 10%

**Denote statistically significant at the 5%.

***Denote statistically significant at the 1%.