

Analysis of Impact of COVID-19 on Stock Prices of Medical Companies Based on Optimal Investment Portfolio Construction

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Abstract. Ever since the outbreak of the COVID-19 pandemic, the focus on investments in medical and pharmaceutical enterprises has risen prominently. Overall, it is expected that the stock market would be negatively impacted by the pandemic, while as it turned out, the development, production, and sale of COVID-19 vaccines have brought about nonnegligible increases in revenues and profits for vaccine producers such as Moderna, Pfizer, and Astra Zeneca. Therefore, in-pandemic investors for medical and pharmaceutical firms desire a comprehensive analysis that takes both the negative influence COVID-19 had on the stock market and the positive impacts the sale of COVID-19 vaccines had on the medical and pharmaceutical industry into account to help with investment decisions. This study chooses five main pharmaceutical and biomedical companies worldwide that have been producing COVID-19 vaccines, and applies Mean-Variance Model to construct optimal investment portfolios and portfolios with minimum variance for both the pre-pandemic period (from January 2019 to December 2019) and in-pandemic period (from January 2020 to April 2022) based on monthly stock prices of these five firms, and analyzes the resulting portfolios by evaluating the influence from both the COVID-19 pandemic and the sale of COVID-19 vaccines. This study shows that for most corporates chosen, the positive impact from the production and sale of COVID-19 vaccines outweighed the negative impact of the pandemic itself, and it suggests that the investors should invest in Astra Zeneca before the pandemic exploded and invest in Moderna after the outbreak of the pandemic.

Keywords: Optimal portfolio; Mean-Variance model; COVID-19 pandemic; COVID-19 vaccines.

1. Introduction

1.1 Background

COVID-19 was detected at the end of 2019, and progressively developed into a global pandemic that greatly influenced the financial and economic activities worldwide. From March 9, 2020, to March 18, 2020, the U.S stock market was circuitied four times under the negative impacts to the financial industry and market caused by the pandemic. However, for investors focusing on medical and pharmaceutical industries, the outbreak of COVID-19 has also brought about potential opportunities for long-term investments, especially regarding corporates that produce COVID-19 vaccines.

The revenue from the sale of COVID-19 vaccines is significant even for large pharmaceutical corporations such as Pfizer. In 2021, 45% of Pfizer's annual revenue was from the sale of COVID-19 vaccines, and for Moderna, a representative for biotechnology companies, the sale of COVID-19 vaccines made up 96% of its annual revenue in 2021 [1]. Such great revenues can undoubtedly impact the stock prices of these medical and biotechnology companies positively, and a question left for the investors is whether the positive impacts on stock prices from the sale of COVID-19 vaccines can surmount the negative influence the pandemic had on the stock market. Such a question can be answered through subsequent analysis and discussions concerning the stock price trend for each of the five corporates chosen.

Assuming that the great revenues produced by the sale of vaccines can create investment opportunities, another lingering question to consider is: how should the investors distribute their principal to maximize their profits while minimizing the risks. To answer such a question, an analysis

based on the Mean-Variance Model will be introduced, which can effectively help us construct an optimal portfolio given the time series of stock prices.

1.2 Related research

There have been various studies researching the impacts COVID-19 and the production of vaccines had on the stock market. In 2019, Su researched why the situation of the U.S stock market was different from that of the overall U.S economy during the COVID-19 pandemic, and concluded that despite the deterioration of the overall economic situation brought about by the pandemic, the S&P 500 increased to even more than the level before COVID-19 because of the combined effect of a series of factors, such as a more optimistic future, the involvement of more individual investors, and some interventions from the policymakers lowering the interests rate [2]. Also, Chan studied how the stock market has reacted positively toward the production and sale of COVID-19 vaccines. According to the research, the mean abnormal stock return was economically and statistically significant at a level of 8.08 points at the beginning of the trial, and for main vaccine producers, the positive effect was even stronger during the beginning of phase three trial [3]. These studies confirmed that there exist multiple factors that eventually resulted in the increasing trend demonstrated by the in-pandemic stock market, represented by the U.S stock market, among which the positive effect of COVID-19 vaccines is significant.

Additionally, Qian and Rasheed researched making predictions on the stock market based on multiple classifiers. Their research pointed out that if stock prices were to be completely random as stated by the efficient market hypothesis, then the prediction concerning stock prices cannot have an accuracy level of more than 50% [4]. However, as is shown by their study, the Dow Jones Industrial Average index is actually predictable because some time periods are not absolutely random [4]. Such a result provides a realistically meaningful foundation for our research, as it illustrates the predictability of certain stock trends, especially for time periods during which the stock market receives enormous external shocks, such as the COVID-19 pandemic and the production and sale of COVID-19 vaccines.

Based on the assumption that stock prices are not unpredictable, it is proper to aim at using specific models, such as the Mean-Variance model, to determine the distributions of future investment portfolios based on historical stock trends. In 1987, Markowitz developed the well-known Mean-Variance mode, which opened investigations about modern investment theory by pointing out that while selecting investment portfolios, the investor should consider both expected return and variances of returns [5]. Such a model has been further developed and applied by plenty of researchers later in constructing optimal portfolios. Thakkar and Chaudhari's research thoroughly examines the benefits of PSO (Particle Swarm Optimization) is an efficient approach for optimal stock portfolio construction, and especially focuses on how stock trends are predicted [6]. According to Syaifudin, stock portfolio management is fundamentally equivalent to a problem of dynamic controlling, and investors should therefore apply Model Predictive control to the Mean-Variance model to form a strategy that can help manage and optimize stock portfolios [7]. On the other hand, concerning stock price forecasting, Ta and Tadesse proposed utilizing long short-term memory (LSTM) network to forecast future stock trends based on data in the past, which improved the sharp ratio and return of the portfolios constructed. This method can be viewed as an improvement of the Mean-Variance model [8]. Last but not least, Davari-Ardakani, Aminnayeri, and Seifi created a model utilizing a multistage portfolio optimization model which employs market risk mitigation. The model was applied to a collection of stocks and the resulting portfolio ended up demonstrating high performance in both reducing risks and enhancing expected return [9].

Although there have been many types of research focusing on developing improved models for constructing optimal stock portfolios based on the Mean-Variance model, very few of them applied the model specifically to analyzing biomedical and pharmaceutical corporates. To thoroughly analyze the impacts of COVID-19 and the vaccines had on stock prices of leading corporates in the medical industry, our research will apply the Mean-Variance model to construct an optimal portfolio and a

portfolio of minimum variance for both pre-pandemic period and in-pandemic period, and then discuss the effects from the worldwide spread of the pandemic as well as development and sale of the vaccines through explaining results given by the model.

Assuming that the great revenues produced by the sale of vaccines can create investment opportunities, another lingering question to consider is: how should the investors distribute their principal to maximize their profits while minimizing the risks. To answer such a question, an analysis based on the Mean-Variance Model will be introduced, which can effectively help us construct an optimal portfolio given the time series of stock prices.

1.3 Objective

The main objective of this research is to construct optimal portfolios and portfolios with minimum variance given five pharmaceutical and biotechnology companies chosen worldwide, then analyze the resulting portfolios to evaluate the influence COVID-19 had on the stock prices of these firms, especially focusing on the impact from the production and sale of COVID-19 vaccines. Models based on Modern Portfolio Theory (MPT) are used, represented by the Mean-Variance Model, and investment suggestions based on the analysis are given.

2. Method

The research focuses on analyzing the impact COVID-19 had on the stock prices of five main stocks in pharmaceutical and biotechnology corporates that have been producing vaccines for COVID-19, which include: Pfizer, Moderna, Johnson & Johnson, China National Pharmaceutical Group Corp (Sinopharm), and Astra Zeneca (AZN). All five stocks were in two portions: the portion before December 2019, before COVID-19, and the portion after December 2019, when COVID-19 started spreading. For each portion, two matrices are constructed using the MPT model. One is the optimal portfolio that can help maximize profits, and the other is the portfolio with minimum variance.

The stock prices were adopted from Yahoo Finance, and for each corporate, average monthly stock prices from 1/1/2019 to 4/1/2022 were collected, then divided into the portion before December 2019 (from 2019/1/1 to 2019/12/1) and the portion after 2019 (from 2020/1/1 to 2022/4/1). The following calculations are based on Markowitz's Mean-Variance analysis [6]:

It is assumed that the weights of four stocks are ω_1 (Moderna), ω_2 (Pfizer), ω_3 (Johnson & Johnson), ω_4 (Sinopharm), and ω_5 (AZN).

Assuming vector 'W' is of the following form:

$$W = \begin{pmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \\ \omega_5 \end{pmatrix} \quad (1)$$

E_r is the expected return for each stock. In that case, we can calculate the expected return for the portfolio by:

$$E_r = (\omega_1 \ \omega_2 \ \omega_3 \ \omega_4 \ \omega_5) \begin{pmatrix} E(r_1) \\ E(r_2) \\ E(r_3) \\ E(r_4) \\ E(r_5) \end{pmatrix} \quad (2)$$

It is assumed the expected return is the annual return of each stock, and the annual return is 12 times the average monthly return. And the monthly return is calculated by:

$$R_t = \ln \left(\frac{P_t}{P_{t-1}} \right) \quad (3)$$

Where P_i is the close price of month i . The global variance of portfolio can be calculated by:

$$\delta_p^2 = W^T S(W) = (\omega_1 \ \omega_2 \ \omega_3 \ \omega_4 \ \omega_5) \begin{pmatrix} \delta_{11} & \delta_{12} & \delta_{13} & \delta_{14} & \delta_{15} \\ \delta_{21} & \delta_{22} & \delta_{23} & \delta_{24} & \delta_{25} \\ \delta_{31} & \delta_{32} & \delta_{33} & \delta_{34} & \delta_{35} \\ \delta_{41} & \delta_{42} & \delta_{43} & \delta_{44} & \delta_{45} \\ \delta_{51} & \delta_{52} & \delta_{53} & \delta_{54} & \delta_{55} \end{pmatrix} \begin{pmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \\ \omega_5 \end{pmatrix} \quad (4)$$

where S refers to the variance-covariance matrix. The standard deviation of the portfolio is:

$$\delta_p = \sqrt{W^T S(W)} \quad (5)$$

Based on the 5-year monthly data, we can generate matrix S. It is a symmetric matrix, and the sharp ratio can be calculated by:

$$S_p = \frac{E(r_p) - r_f}{\delta_p} \quad (6)$$

Eventually, portfolios were constructed for both time portions (before and after the spread of COVID-19), and further tests on the two different optimal portfolios were performed to analyze the overall impact COVID-19 had on pharmaceutical and biotechnology corporates that have been producing vaccines for COVID-19.

3. Results

The historical data from 1/1/2019 to 12/1/2019, including average monthly and annual returns and average monthly and annual variances, is shown in Table 1.

Table 1. Summary of Pre-pandemic Annual & Monthly Return and Variance

	Moderna	Pfizer	Johnson & Johnson	Sinopharm	AZN
average monthly return	0.015	-0.004	0.011	-0.017	0.031
average annual return	0.179	-0.048	0.130	-0.203	0.374
average monthly variance	0.007	0.007	0.009	0.003	0.005
average annual variance	0.086	0.085	0.107	0.033	0.062

Notes: Results have been rounded to 3 decimal places in all tables.

The historical data from 1/1/2020 to 4/1/2022 is shown in the Table 2. In addition, based on the historical data in different time periods, it can calculate two different matrices, as shown in Table 3 and Table 4.

Table 2. Summary of In-pandemic Annual & Monthly Return and Variance

	Moderna	Pfizer	Johnson & Johnson	Sinopharm	AZN
average monthly return	0.076	0.018	0.009	-0.012	0.015
average annual return	0.912	0.219	0.110	-0.142	0.184
average monthly variance	0.076	0.031	0.010	0.017	0.004
average annual variance	0.912	0.372	0.130	0.207	0.048

Table 3. Variance-covariance Matrix for Data from 1/1/2019 to 12/1/2019

	Moderna	Pfizer	Johnson & Johnson	Sinopharm	AZN
Moderna	0.039	-0.002	0.001	-0.001	-0.001
Pfizer	-0.002	0.003	0.001	0.0003	0.001
Johnson & Johnson	0.001	0.001	0.002	0.000	0.001
Sinopharm	-0.001	0.000	0.000	0.006	0.002
AZN	-0.001	0.001	0.001	0.002	0.003

Table 4. Variance-covariance Matrix for Data from 1/1/2020 to 4/1/2022

	Moderna	Pfizer	Johnson & Johnson	Sinopharm	AZN
Moderna	0.074	0.008	0.001	0.003	0.004
Pfizer	0.008	0.008	0.003	0.001	0.002
Johnson & Johnson	0.001	0.003	0.003	0.001	0.002
Sinopharm	0.003	0.001	0.001	0.012	0.002
AZN	0.004	0.002	0.002	0.002	0.004

Then, the optimal portfolios and minimum variance portfolios for both time periods can be calculated, and we denote them as portfolio A and portfolio B, as shown in Table 5 and Table 6.

Table 5. Pre-pandemic Optimal Portfolio and Global Minimum Variance Portfolio (**Portfolio A**)

	Optimal Portfolio	Global Minimum Variance Portfolio
Moderna	0%	3.8%
Pfizer	0%	16.6%
Johnson & Johnson	0%	45.9%
Sinopharm	0%	14.4%
AZN	100%	19.4%
Sum	100%	100%
Ex return	0.374	0.102
std	0.056	0.035
sharp ratio	0.000	-7.710

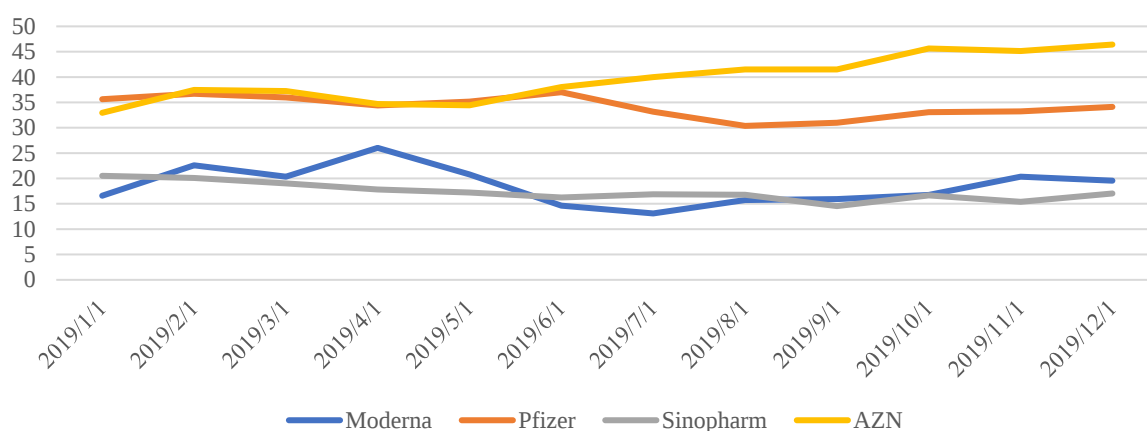
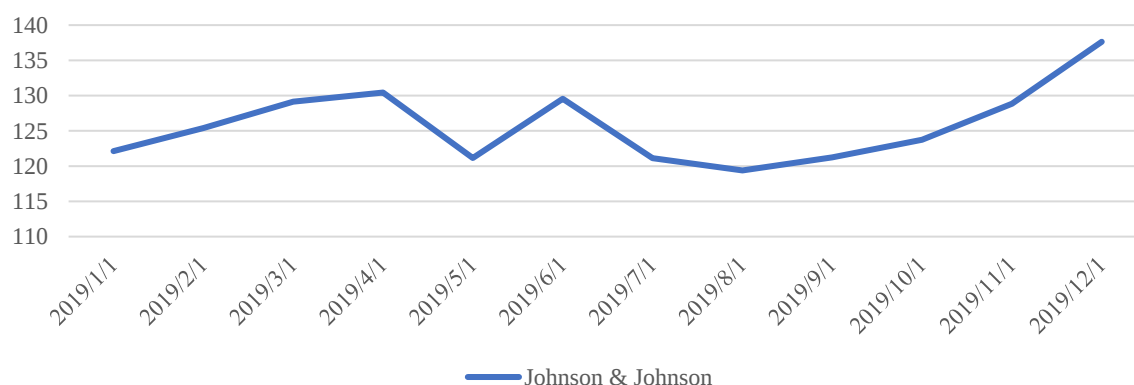
Table 6. In-pandemic Optimal Portfolio and Global Minimum Variance Portfolio (Portfolio B)

	Optimal Portfolio	Global Minimum Variance Portfolio
Moderna	100%	0.1%
Pfizer	0%	7.1%
Johnson & Johnson	0%	48.5%
Sinopharm	0%	10.8%
AZN	0%	33.5%
Sum	100%	100%
Ex return	0.912	0.116
std	0.271	0.050
sharp ratio	2.683	-1.344

4. Discussion

Based on results shown by the global minimum variance portfolios and optimal portfolios, to maximize profits and minimize variances, before December 2019, all capital should be put into AZN, while after 2019, all funds should be put into Moderna. The investment suggestions were given by the optimal portfolio and global minimum variance portfolio can be different from each other. Before December, portfolio A suggested putting all capital in ANZ, while after December, portfolio B suggests putting all capital in Moderna,

The first step to analyze results given by the portfolios is to graph the stock prices before and after December 2019. To illustrate the trend, Johnson & Johnson is graphed separately:


Figure 1. Stock prices vs Time during Pre-pandemic Period for Four Firms (exclude J&J)

Figure 2. Stock prices vs Time during Pre-pandemic Period for J&J

Based on Figure 1 and Figure 2, from January 2019 to December 2019, none of the stocks demonstrated a significant increase or decrease. The price for J&J increases with the greatest variance among the five, prices of Sinopharm and Pitzer both demonstrated decreasing trends, and the price of Moderna only increases very little and with a comparatively large variance. AZN, however, increased relatively steadily during the one year, so investing a large portion of the total fund into AZN before December 2019 turns out to be reasonable.

However, when we include prices from January 2020 to March 2022 and start observing stock prices from a more comprehensive perspective, we can get a different answer. To illustrate the trend, Modern and Johnson & Johnson are graphed separately:

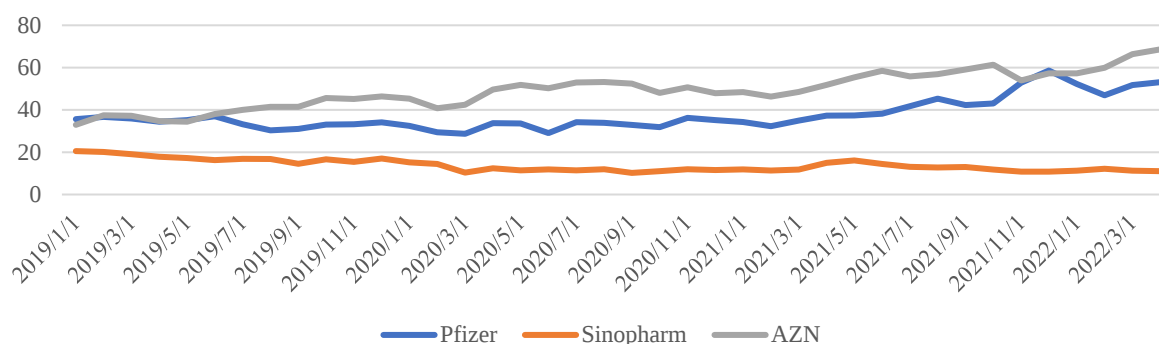


Figure 3. Overall Stock prices VS Time for Pfizer, Sinopharm, and AZN

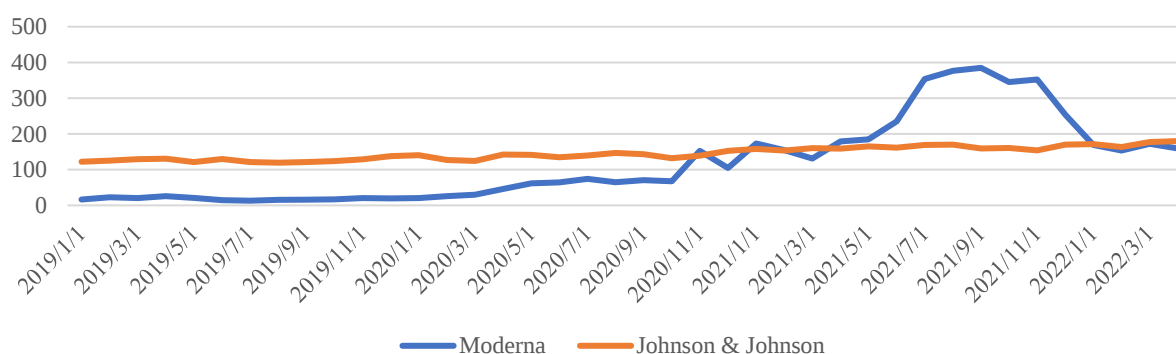


Figure 4. Overall Stock prices VS Time for Moderna and J&J

In the illustrations above, the price of Moderna demonstrated a sharp increase from October 2020 to September 2021. Although after November 2020, the stock price of Moderna fell sharply back to about 150 from around 380 in half a year, the increase in the price is still much more significant than the increases in prices of the other four firms. Therefore, the optimal portfolio after 2019, which suggests investing all capital to buy Moderna, turns out to be reasonable.

One potential explanation for the significant increase in Moderna's stock price from November 2020 to September 2021 is that the development of the COVID-19 vaccine has brought about great profits and confidence in Moderna as a leading role in the pharmaceutical and biotechnology industry. On 30, April 2021, the COVID-19 vaccine produced by Moderna became the fifth COVID vaccine listed for emergency use by World Health Organization (WHO, 2021), and on 18, December 2021, the vaccine became the second COVID-19 vaccine authorized for emergency use by U.S Food and Drug Administration (FDA, 2021). Since vaccines produced by AZN, Johnson & Johnson, and Pfizer were approved by WHO earlier than the vaccine produced by Moderna, the approval from WHO is likely irrelevant to the increase in Moderna's stock price. The authorization from the FDA is more likely the cause of the enormous growth in Moderna's stock price because it took place at the end of 2020, which matches the beginning of the period during which Moderna's stock price soared.

However, notice that Pfizer and Moderna are both biotechnology corporates from the U.S that produce mRNA vaccines for COVID-19, and the vaccine produced by Pfizer was also approved by the FDA for emergence use as early as 11, December 2020, 7 days ahead of the approval for Moderna's vaccine. Therefore, if the development of the COVID-19 vaccine were the leading factor that resulted in the tremendous growth in Moderna's stock price, we would naturally expect similar growth to occur in Pfizer's stock price right after the beginning of 2021. As it turned out, the stock price of Pfizer increased from around 31.29 to around 42.31 from January 2021 to September 2021, which is an approximately 35% increase in price, while the stock price of Moderna increased from around 173.16 to 384.86 during the same period, which is an approximately 122% increase in price. The difference between the growth rate of the stock prices of Moderna and Pfizer suggests that the development of the vaccine is probably not the only factor that has caused such a significant increase in Moderna's stock price.

Another important factor leading Moderna's stock price to increase more significantly than Pfizer's is the difference in their volumes. Pfizer, one of the largest pharmaceutical companies in the world, had annual revenue of \$81.3 billion in 2021 [10]. Moderna, as a biomedical company with a relatively small volume, had annual revenue of \$18.5 billion, only 22.7% of Pfizer's annual revenue [10]. Given such a great difference in volumes, the same revenue from the COVID-19 vaccine should in much a smaller percentage increase in Pfizer's annual revenue, compared with the percentage increase in Pfizer's annual revenue. In fact, in 2021, 45% of Pfizer's total revenue was from the sale of COVID-19 vaccines worldwide, and for Moderna, the sale of COVID-19 vaccines accounted for 96% of its annual revenue in 2021 [1]. Therefore, it is expected that the revenue earned through the sale of COVID-19 vaccines should generate a greater positive effect on Moderna's annual income than on Pfizer's annual income, thereby causing Moderna's stock price in 2021 to increase more significantly than Pfizer's.

Finally, despite the model suggesting all in Moderna during the in-pandemic period, to effectively hedge and reduce the risk, investors should also consider distributing part of their capital investing AZN, because the positive effect brought about by the production of COVID-19 vaccines will diminish in the long term, making all-in Moderna riskier. The growth of AZN's stock price has been relatively stable both before and after the start of the pandemic as shown by our first model, and as a British corporate, its stock price is not as greatly affected by the overall economic situation in the United States as Moderna and Pfizer. Additionally, AZN is one of the leading pharmaceutical and biotechnology companies and the main producer of COVID-19 vaccines, which makes AZN an ideal role for investment in the long run.

5. Conclusion

This study focuses on the influences COVID-19 and the development and sale of COVID-19 vaccines had on stock prices of medical and biomedical corporates. As shown in the study, all five stocks have been influenced to some degree. Overall, the impact of the development and sale of COVID-19 vaccines outweighed the influence of the pandemic, leading to price rising in four out of the five stocks. Specifically, the price of Moderna increased a lot after 2019 under the large portion of revenues from its vaccine production, and the price of Sinopharm dropped steadily, probably because the pandemic influenced economic situations in the U.S and China differently. The prices of the other three stocks increased comparatively steadily. In such a case, the optimal portfolio suggests all-in AZN during the one-year pre-pandemic period, and all-in Moderna during the in-pandemic period. Based on the reality, because of the long-lasting epidemic around the world, there is a continuous need for vaccines. Therefore, investing most capital into Moderna is reasonable. However, taking into account the need for hedging and reducing overall risks, it is suggested that investors should distribute part of their investments to AZN, which possesses the steadiest growth in stock price among the five corporates chosen.

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