Unraveling the Effect of COVID-19 on Portfolio Optimization Using Quantum Algorithms

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***Abstract*— Portfolio optimization is one of the important problem classes in finance sector. As the world economy recovered and reaching the pre-COVID levels and is still continuing to grow, it is imperative to understand what kind of impact COVID-19 had on portfolio optimization and how quantum computers can be used in doing so. Hybrid quantum algorithms like variational quantum eigen solver (VQE), quantum approximate optimization algorithm (QAOA) have been tried for identifying optimal portfolios. In the present work, we employ these algorithms to carry out portfolio optimization for different time intervals (which includes pre and during COVID-19 periods) and unravel the impact of COVID-19 on the same, across different industries.**

Our results show that the companies' stocks were growing steadily more on a sideways movement from 2016-2017. The stocks start to pick momentum from 2018-2019 and in 2020 early months as dip can be observed, however all the stocks recover to normal levels and even reaching lifetime highs from second half of 2020. Keywords—Quantum Algorithms, Portfolio Optimization, Covid-19, Markowitz model, QAOA, VQE

I. Poster Relevance

When quantum computers have about 300 qubits it can process more information than there are total number of atoms in the entire universe. When this happens
the stage will be all set to solve problems that are intractable to classical computing one after the other. There is still enormous potential for us to use the quantum computers available to us in this NISQ (Noisy Intermediate Scale Quantum Computing, coined by John Preskill in 2018). It is estimated that finance sector will be one of the largest first beneficiaries of this NISQ era computing. In this context, it is important to imperative the quantum algorithms that works best for certain class and kind of problems. Portfolio optimization is one of the important classes of optimization problems encountered in finance sector. In this work we have two major objectives namely, i) unravelling the effect of COVID-19 on various portfolios by means of quantum algorithms and compare it with the classical Markowitz's approach and ii) evaluate the quantum algorithms such as VQE and QAOA with reference to the classical Markowitz's theory. Both of these objectives are of high significance towards quantum computing as it can help us validate the algorithms and open for much broader discussion and application.

II. Extended Poster Abstract

A. Introduction

The unforeseen COVID-19 pandemic delivered a huge blow to the global economy. Especially, it left the financial sector almost toppled. As the world economy recovered and reaching the pre-COVID levels and is still continuing to grow, it is imperative to understand what kind of impact COVID-19 had on portfolio optimization[1] in order to be able to operate in line with the trend. Understanding the trend in portfolio during the pandemic not only helps in learning how it really evolved, it also helps us prepare for any such possible event in the future.

There are several algorithms that have been developed to identify optimum portfolios such as Markowitz model, genetic, firefly, fuzzy approach algorithms and many more. These algorithms can be in a sense termed classical, implying they can be run efficiently on classical computers. However, with the advent of quantum computing we are posed with the challenges of implementing these well-known algorithms on these quantum computers. Quantum computing harnesses the distinct features of quantum regime such as superposition of states, entanglement and interference to perform computation. Therefore, the so-called classical algorithms that do not use the power of quantum regime are not directly implementable on quantum computers. Although in its nascent stages, quantum computing has been shown to be more advantageous than its classical counterparts.

Hybrid quantum algorithms like variational quantum eigen solver (VQE), quantum approximate optimization algorithm (QAOA) have been tried for identifying optimal portfolios.[2],[3] In the present work, we employ these algorithms to carry out portfolio optimization for different time intervals (which includes pre and during COVID-19 periods) and unravel the impact of COVID-19 on the same,

across different industries constituting consumer electronics, technology, e-commerce and retail, oil and OTT platforms.

B. The Approach

In the work we have made an effort to understand the effect of the pandemic COVID-19 on the optimal portfolios. In order to be able to perform the analysis, the time line has been segregated in the following manner as shown in the table below. We have approximated the timeline between 01-01-2020 to 12-31-2021 to be completely influenced by the effect of COVID-19 due to lockdown around the various countries from different continents from around the world. This approximation serves the purpose as it gives us a data point for the timeline affected by the COVID-19. The Non-COVID (1) and (2) are considered with each having 24 months which matches with the COVID-19 affected duration. Therefore, the timeline 2016-2019 has been divided into two different sections as 01-01-2016 to 12-31-2017 and 01-01-2018 to 12-31-2019 in order to obtain data points or the non-COVID-19 timelines. Yahoo finance service has been used to collect data for the timelines discussed earlier. For carrying out quantum computing calculations IBM's Qiskit has been employed. Quantum algorithms like variation quantum eigensolver (VQE) and quantum approximate optimization algorithm (QAOA) have been used to identify the optimal portfolios. To corroborate the results obtain using quantum algorithms, calculation based on Markowitz's modern portfolio theory (MPT) has been applied on the datasets using the Qiskit and Python.

The stocks which we have analyzed are as follow(see also [5]):

Retail & E-comm	**Technology**	**Automotive**	**Oil & Gas**	**Airways & Hospitality**
Costco (COST)	Google (GOOG)	General Motors (GM)	Shell (SHEL)	Marriott International (MAR)
Amazon (AMZN)	IBM (IBM)	Mercedes (DMLRY)	Conoco Phillips (COP)	Choice Hotels (CHH)
Target (TGT)	Intel (INTC)	Tesla (TSLA)	Marathon Oil (MRO)	LTC Properties (LTC)
Walmart (WMT)	Microsoft (MSFT)	Ford (F)	Chevron Corp. (CVX)	Alaska Air (ALK)

Table 1: Stocks Analyzed in the study

C. The Theory

Markowitz Modern Portfolio Theory:

This theory takes into account two main concepts:

1. The investor's goal is to maximize return for any level of risk
2. Risk can be reduced by diversifying a portfolio through individual, unrelated securities.

We take the variance of the rate of return of an instrument is taken as a surrogate for its volatility.

The Risk can further be divided into two parts

1. Systematic Risk:

This refers to market risks that cannot be reduced through diversification or the possibility that the entire market and economy will go into losses that negatively affect investments.

2. Unsystematic Risk:

Also called specific risk, unsystematic risk is specific to individual stocks, meaning it can be diversified as you increase the number of stocks in your portfolio.

Variational Quantum Eigensolver:

VQE is Quantum-classical algorithm. It aims to find an upper bound of the lowest eigenvalue of a given Hamiltonian.
VQE has two fundamental steps:

1. Prepare the quantum state $|\Psi(\theta)\rangle$ often called the *ansatz*.
2. Measure the expectation value $\langle\Psi(\theta)|H|\Psi(\theta)\rangle$.

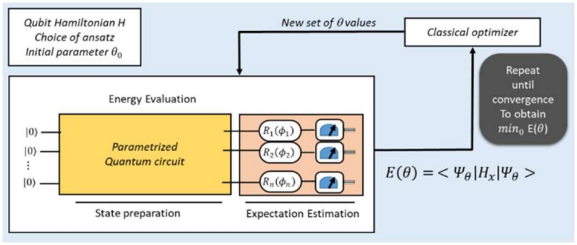

Figure 1: Variational Quantum Eigensolver

Quantum Approximate Optimization Algorithm:

The VQE algorithm applies classical optimization to minimize the energy expectation of an ansatz state to find the ground state energy. QAOA takes the approach of classical approximate algorithms and looks for a quantum analog that will also produce a classical bit string x∗ that with high probability is expected to have a good approximation ratio α. The answer is to find a state |ψ> which would maximize <C> as a solution for finding a |z> which will maximize C(z). [4]

$$\langle C \rangle = \langle \Psi | C | \Psi \rangle = \sum_{z \in \{0,1\}^n} f(z)|a_z|^2 \leq \sum_{z \in \{0,1\}^n} f(z')|a_z|^2 = f(z') \sum_{z \in \{0,1\}^n} |a_z|^2 = f(z')$$

S.No.	**Item**	**Time line**
1	Non COVID-19 (1)	01-01-2016 to 12-31-2017 (24 months)
2	Non COVID-19 (2)	01-01-2018 to 12-31-2019 (24 months)
3	COVID	01-01-2020 to 12-31-2021 (24 months)

Table 2: Timelines analysed based on Covid-19 impact

III. CONCLUSION AND RESULTS

The optimal portfolios obtained using both quantum and classical algorithms reveal two kinds of information namely; i) the effect of COVID-19 on the selection of optimal portfolio based on the theoretical foundations of mean variance ii) the scope of improvement in the ansatz and the objective function.

i.) COVID-19:

The trends in the stock market can be a direct indicator of the sentiments and emotions of the investors and the economy in general. As COVID-19 started rapidly spreading in US, the fear in the minds of people and the government led to the halt of various economic activities and a complete lockdown was imposed to control and contain the further spread of the virus.

The increase in volatility in stock markets worldwide started in the last week of January 2020, with many countries reporting the first cases of novel coronavirus. After January 30, 2020, India's NIFTY 50 shows an increase in volatility. With high volatility in NSE and NYSE, stocks across the sectors reacted differently to COVID-19 based on the effect it has on the operations of the business. We can generalize the outcomes of the pandemic as follows

The best performing industries were companies operating in the information technology (IT) sector have come out even stronger post the pandemic, with the IT S&P 500 sector index sitting at almost 65 percent above early 2020 levels as of November 2021. As people become more reliant on IT and IT-enabled services while people started finding ways to pass time, platforms such as Amazon and Google (from our analysis) started showing potential growth. The reason being as shops were shuttered, and social gatherings were heavily restricted due to the pandemic, online services such as shopping, and video streaming were unforeseen high in demand. The success of the IT sector is also reflected in the performance of global share markets during the coronavirus pandemic, with tech-heavy NASDAQ being the best performing major market worldwide.

On the other hand, energy companies were the worst during the pandemic, with the S&P 500 sector index value sitting below its early 2020 value as late as July 2021. This reflects the fact that many oil companies (e.g.) were among the share prices suffering the most significant declines over 2020. A primary driver for this was the falling demand for fuel, which fell in line with the reduction in tourism and commuting caused by lockdowns all over the world. However, increasing COVID-19 vaccination rates throughout 2021 led to lockdowns being lifted and global tourism such as Chevron and Marriott. As with the reopening, demand has again risen - reflected by the recent increase in the S&P 500 energy index and QAOA analysis.

ii.a) Comparison of VQE and Classical Markowitz Theory

In all the results of VQE, two eigenstates can be identified where in one of the states is lowest and the second one is almost same as the lowest one (for eg. -0.0012 and -0.0011 in case of Non-Covid1 for Retail corresponding to the eigenstates |0 1 0 0> and |0 0 0 1>) which shows that we can select two portfolios. These eigenstates are almost degenerate in nature implying both are optimal portfolios that can be selected for the investment. However, their coefficients or the weightage of the these almost degenerate (|0 1 0 0> and |0 0 0 1>) states is largely varied as can be seen from their probability of 0.9978 and 0.0015. If one were to consider the result solely based on the energy of the eigenstates then one can readily argue that the optimal portfolio to be selected are |0 1 0 1> and that is exactly what is prescribed by the classical computing of Markowitz theory (|0 1 0 1). However, the hypothesis is defeated when one strictly goes by considering the probability alone.

Therefore, while the ansatz and the objective function generated in Qiskit when minimized using the VQE algorithm is able to identify the portfolios (eigenstates and their corresponding eigen energies) on par with the classical Markowitz's mean variance method, but it does not evaluate the coefficients in the optimal way. Therefore, the results suggests that there is a scope of improvement in how the problem is formulated in terms of ansatz implying the ansatz can be corrected to be parallel with the classical Markowitz approach.

ii.b) Comparison of QAOA and Classical Markowitz Theory

From the result by QAOA, the scenario is similar to the VQE results. We shall consider the same NC1 for retail for efficient comparison However, instead of almost doubly degenerate states in VQE there are four eigenstates are obtained after optimization with almost equal probability (|0 1 0 0>, |0 0 0 1> , |1 0 0 0> and |0 0 1 0> with probabilities 0.236, 0.2358, 0.2354, 0.235 respectively.). However, the eigenvalues of the energy states |0 1 0 0>, |0 0 0 1> are -0.0011 almost doubly degenerate which readily matches with the portfolios suggested by the classical Markowitz theory. But the coefficients determined by the

QAOA are almost same tempting one to lead to conclusion that we can select all the stocks. This is obviously in contrast with classical Markowitz theory. Therefore, much similar in the case of VQE we have a scope for improvement in the ansatz which to predict along the lines of classical Markowitz theory.

In summary, in this work we have unravelled the effect of COVID-19 on the portfolio optimization using quantum algorithms such as VQE and QAOA and the results obtained qualitatively agrees well with portfolios suggested by the classical Markowitz's modern portfolio theory. However, as described in the previous section, the trend seen in the results obtained using VQE and QAOA, suggests that there is a scope for fine tuning of the ansatz and problem formulation to obtain the results that is on par with the classical Markowitz theory.

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Outline

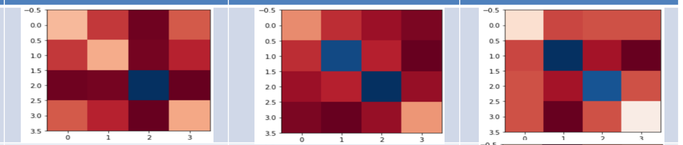
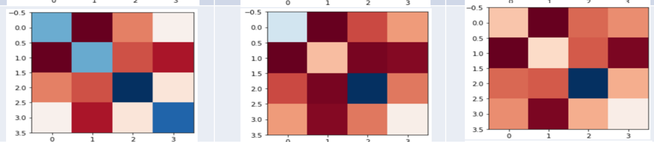
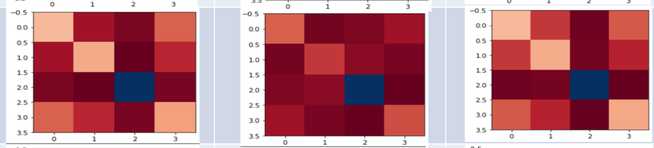
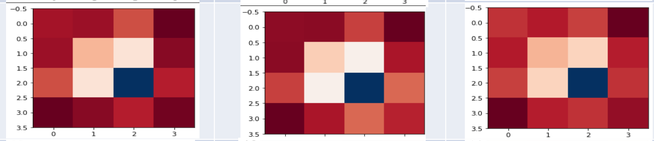
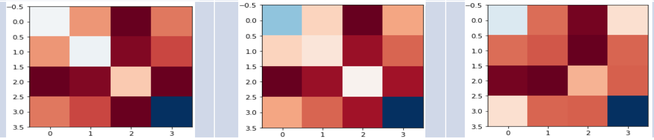
1. Portfolio Optimization- Maximize Returns and Minimize Risk
2. Classical Algorithms- Markowitz, Numpy EigenSolver
3. Quantum Computing-VQE, QAOA
4. Impact of Covid-19 on portfolio optimization

Abstract

The unforeseen COVID-19 pandemic delivered a huge blow to the global economy. This poster elaborates the effect of COVID-19 on the portfolio optimization across different industrial sectors retail, technology, automotive, oil & gas, airlines & hospitality.

Portfolio Optimization is to select best portfolios with an objective to maximize the return value and minimize the risk factor. To understand the trend in Portfolio Optimization pre covid-19 and during covid-19 three time intervals are considered and the results from different quantum algorithms are compared with classical results. The quantum algorithms used are Variational Quantum Eigen solver (VQE), Quantum Approximate Optimization Algorithm (QAOA).

Covariance Graphs

Pool	Non-COVID 1 (Jan '16-Dec '17)	Non-COVID 2 (Jan '18-Dec '19)	COVID (Jan '20-Dec '21)
Retail			
Technology			
Automotive			
Oil & Gas			
Airlines & Hospitality			

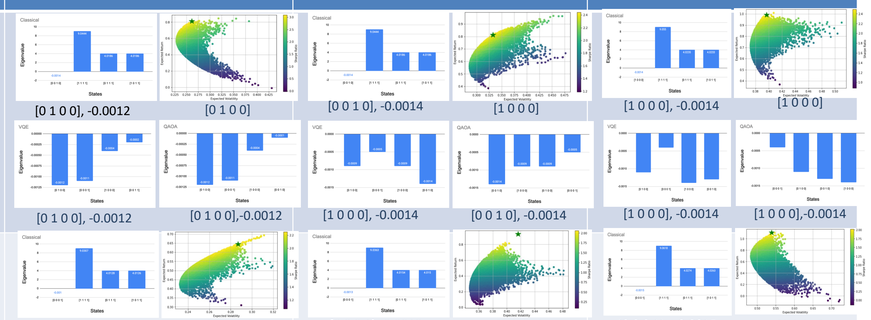
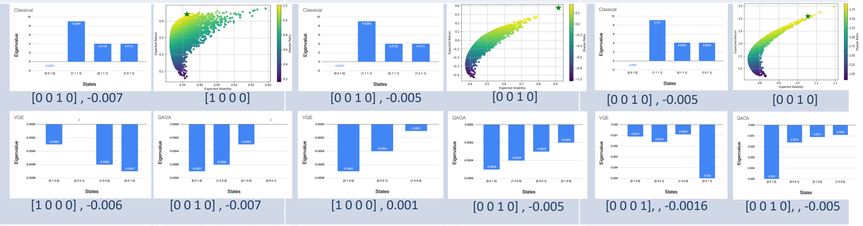
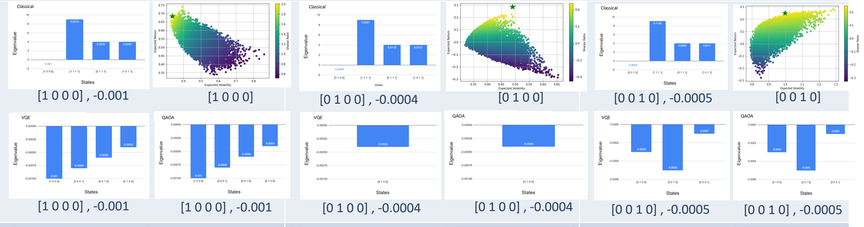
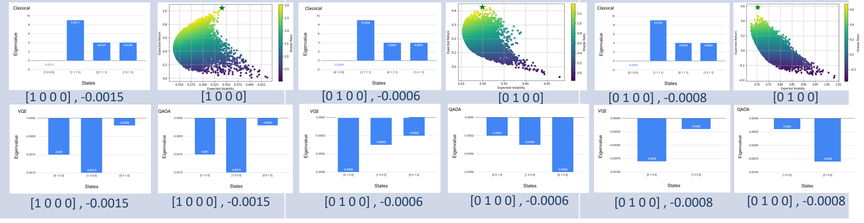
Methods

Main objective of portfolio optimization is:
1. The investor's goal is to maximize return for low level of risk
2. Risk can be reduced by diversifying a portfolio through individual, unrelated securities
Initially, the problem of portfolio optimization is translated into the form of variation circuit called ansatz to enable the quantum computer to perform optimization on the objective function.
VQE is Hybrid Quantum-classical algorithm. VQE which is developed on Variational Principle calculates the lowest energy which corresponds to the optimal portfolio
It aims to find an upper bound of the lowest eigenvalue of a given Hamiltonian.

Methods Cont..

VQE has two fundamental steps:
1. Prepare the quantum state $|\Psi(\theta)\rangle$
2. Measure the expectation value $\langle\Psi(\theta)|H|\Psi(\theta)\rangle$
3. Optimize the parameter θ on classical computer and generate the updated wavefunction
4. Calculate the expectation value again for the updated wavefunction
5. Iterate until convergence criteria is met
QAOA is widely popular method for solving combinatorial optimization problems. The VQE algorithm applies classical optimization to minimize the energy expectation of an ansatz state to find the ground state energy.

Results

Pool	Non-COVID 1 (Jan '16-Dec '17)	Non-COVID 2 (Jan '18-Dec '19)	COVID (Jan '20-Dec '21)
Retail			
Technology			
Automotive			
Oil & Gas			
Airlines & Hospitality			

The answer is to find a state $|\psi\rangle$ which would maximize <C> as a solution for finding a $|z\rangle$ which will maximize C(z).

$$\langle C \rangle = \langle \Psi | C | \Psi \rangle = \sum_{z \in \{0,1\}^n} f(z)|a_z|^2 \leq \sum_{z \in \{0,1\}^n} f(z')|a_z|^2 = f(z') \sum_{z \in \{0,1\}^n} |a_z|^2 = f(z')$$

Impact of Covid

Pool	Non-COVID1	Non-COVID2	COVID	Reason
Retail (Costco, Amazon, Target, Walmart)	COST	TGT	COST	COST & TGT are major market share holders and as they open new stores to at more locations and while offering the products at affordable prices, drives the growth of COST.
Technology (Google, IBM, Intel, Microsoft)	GOOG	GOOG	MSFT	GOOG remains the most used IT service in the world in terms of apps and browsers. MSFT also control majority of the OS used worldwide, while launching its own hardware products.
Automotive (General Motors, Mercedes, Tesla, Ford)	GM	TSLA	TSLA	GM owned a large market cap in automotive around 2016, but as people accept EV as a better alternative to gas powered engines, and look for greener ways of transport which is also more technology wise advanced, TSLA soars after 2017.
Oil & Gas (Shell, Conoco Phillips, Marathon Oil, Chevron Corp.)	CVX	COP	CVX	CVX & COP control majority of gas and oil extraction in us and also in some parts of the world. As they continue to innovate and expand in the hydrocarbon fuel markets.
Airlines & Hospitality (Marriott Int, Choice Hotels, LTC Properties, Alaska Air)	MAR	CHH	MAR	MAR and CHH remains people's first choice. As they continue to grown and make newer and more luxurious properties. The in them considerably increases with time

Conclusions

In all the results of VQE and QAOA, two eigenstates can be identified one state is lowest and the second is almost same as the lowest. This infers that we can select two portfolios. These eigenstates are almost degenerate in nature implying both are optimal portfolios. While the ansatz and the objective function generated in Qiskit using the VQE and QAOA is able to identify the portfolios (eigenstates and their corresponding eigen energies) in good agreement with the classical Markowitz's mean variance method, but it does not evaluate the coefficients in the optimal way.

Therefore the results suggests that there is a scope of improvement in how the problem is formulated in terms of ansatz implying the ansatz can be corrected to be parallel with the classical Markowitz approach.

We have a scope for improvement in the ansatz which to predict along the lines of classical Markowitz theory.

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