Blockchain in Healthcare

by

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Abstract

Blockchain technology has played an important role in the cryptocurrency markets, providing networks with collaborative and tamper-proof benefits for handling transactions. While the financial applications of blockchain have been explored most heavily, other industries have yet to fully implement and reap the benefits of blockchain technology. This study aims to identify and measure the benefits after the implementation of blockchain by healthcare companies. The difference in differences approach is conducted on two pairs of companies in different sectors of the healthcare industry. The return coefficients show notable outperformance for companies using blockchain, but the limitations surrounding an available sample size impacts the statistical significance of the study.

Introduction

Blockchain technology is a peer-to-peer network that provides the healthcare industry with the opportunity to improve data management for patients, clinical trials, supply chains, and physicians. This can result in economic and social benefits for the healthcare industry via reduced identity errors, chargeback or pricing mistakes, and counterfeit drugs. However, the technology's early stages and ongoing pilot programs generate uncertainty and skepticism over whether it will be able to solve ongoing problems in the healthcare industry. The technology also suffers from obstacles such as interoperability, privacy and supply chain traceability, and gateway problems. Focusing on blockchain in the healthcare space is meant to help researchers and managers understand the technology's potential implications. This paper will address the uncertainty surrounding blockchain by conducting a difference in differences analysis on pair companies' stock performance using and not using blockchain technology.

The United States spends about 20% of its GDP on healthcare, more than any other country. The healthcare industry, specifically in the United States, is victim to many inefficiencies including high and rising costs, supply chain failures, electronic healthcare record (EHR) inaccuracies, poor data provenance, and misleading clinical trial data. The paper will attempt to explain what blockchain is and will also identify some of the pitfalls of blockchain technology in the healthcare industry. The paper will also highlight past academic literature such as studies with simulated blockchain environments and theses proposing permissioned blockchain prototypes for the healthcare industry. The paper's quantitative component will analyze two company pairs in which one company uses blockchain technology and another does not. A difference in differences approach will help reveal the link between the implementation of blockchain and stock performance. Ultimately, the paper explores how blockchain can impact companies in the healthcare industry to help better understand why companies and institutions should consider adopting or refrain from implementing blockchain.

Blockchain

What is Blockchain

Blockchain is often described as being immutable, anonymous, decentralized, and collaborative (Namasudra and Ganesh, 2021). Many of these attributes, however, often refer to public permissionless chains that are less adequate for the healthcare industry. In general, blockchains are tamper-proof ledgers that store transactional records into blocks. These blocks are then connected to previous blocks via a unique identifier, which, when changed, can provide evidence to the network that a block has been tampered with (Materese, 2022). Before Bitcoin and blockchain, processes often relied (and still rely) on centralized systems as a means of maintaining trust. Oftentimes people associate blockchain with cryptocurrencies, given the technology's underlying role in these digital assets. The association with popular blockchains like Bitcoin and Ethereum has helped highlight the technology's use cases across industries. Alternate coins like Litecoin and Ripple have become popular mining and investment alternatives to these larger institutionalized cryptocurrencies, but are built using much of the same architecture. The Bitcoin and Ethereum networks, for example, have different structures enabling their proof-of-work (PoW) and proof-of-stake (PoS) architectures, respectively.

Proof-of-work architecture requires miners to buy equipment, run it indefinitely, and incur energy costs to undertake computational work as a means of obtaining a block reward, or tokens. In proof-of-stake, a newer type of architecture, validators need only hold tokens that they stake for a chance to earn additional tokens after validating new transactions. PoS was developed as a response to PoW's limitations. Despite PoW's ability to maintain a secure decentralized blockchain, it is energy-intensive and unable to accommodate the scale needed for a large number of transactions.

IBM's Hyperledger Fabric, however, does not use PoW or PoS, since it does not need cryptocurrency to reach a consensus or need computers verifying transactions around the clock. Rather, Hyuperledger makes use of a Proof of Authority (PoA) architecture which allows for verification on a permissioned consortium network where participants are already known to each other. In this system, transactions are verified by approved accounts, or validators, onto the main chain rather than forks. These very validators also vote to add or remove validators. Using identity as a stake allows for a comparatively faster transaction rate versus PoW and PoS (Dawson, 2022).

Types of Cryptography

There are two main types of cryptography: symmetric and asymmetric. In symmetric cryptography, there is a single public key that is shared with those who need it. The public key is used to both lock and unlock a document. While practical, this type of encryption offers limited functionality with respect to security and authentication. Under asymmetric encryption there exists a public and private key. The public key is used to encrypt the content and the private key of the recipient is the only available key that can decrypt, or unlock, the content. This process makes asymmetric encryption much more secure vis-a-vis symmetric encryption. Healthcare data demands a greater level of security than other types of data, thereby making asymmetric encryption a preferred choice over symmetric encryption in healthcare blockchain applications.

Encryption in general allows users to authenticate a message. For example, a pharmacy can authenticate whether a script was created and “signed” by a patient’s doctor.

Types of Blockchain

Blockchain networks take different forms which provide network users varying levels of permissions, functionality, scalability, and transparency. In public blockchain networks, there is an enhanced level of independence and transparency, however, it suffers from scalability issues. Popular examples of public, or permissionless, networks include Bitcoin. These allow anyone to join thereby strengthening the decentralized characteristic of the network.

Private blockchain networks are permissioned meaning they are controlled by a select group of administrators. This dilutes the element of decentralization in a blockchain network but allows for more efficient performance versus a public blockchain. Ripple is a notable example of a private blockchain that has been scrutinized by the Securities and Exchange Commission. Ripple has gained notoriety for processing transactions more quickly than other digital assets and at fractions of a cent.

A federated, or consortium, network offers new nodes the opportunity to join without having to start from scratch. Companies, for example, can be onboarded onto the network with greater ease, allowing for maximum scalability. As a result, the network is governed by multiple institutions rather than a single user.

A hybrid blockchain leverages the architecture of public and private blockchains, thereby resulting in numerous benefits. IBM has developed a network called Food Trust that allows farmers, wholesalers, distributors, and others to take part in the network. This design allows for the scalability and access control of a private network without compromising performance. The private component of this network, however, still reduces the transparency and decentralization present in a public blockchain.

IBM provides blockchain services to healthcare and life sciences companies. Healthcare services include verifying health credentials, finding reputable suppliers, and safeguarding medications. IBM developed Trust Your Supplier, a blockchain-enabled system that provides a digital identity. This immutable record allows for accelerated onboarding, streamlined supplier validation that results in lower procurement costs, and connections to ISO certification databases that reduce compliance risks.

Life sciences services include medication recall notifications, industrialized cell and gene therapy, and vaccine distribution networks. Merck leveraged IBM to implement blockchain into medical leaflets as part of a pilot program for the FDA's Drug Supply Chain Security Act (DSCSA). This program showed that manufacturers were able to trigger a recall alert at the lot level that notifies downstream network members who have taken possession of it. Ultimately, this process helped reduce the recall notification process from days to seconds (IBM).

Private permissioned blockchains, like IBM Hyperledger, authorize a limited number of readers and writers, a stark contrast to a public permissionless blockchain that allows anyone to join or leave. Healthcare data such as patient medical records are sensitive making private permissioned blockchains a preferred architecture for the industry. Only designated members on the network, rather than an entire network of unvetted members, should have access to data like patient medical records, pharmaceutical supply lots, and insurance claims. Having permissions allows for greater data integrity whereas a permissionless blockchain would allow any node to add inaccurate transactions or misuse data. Private permissioned blockchains have regulatory implications, especially under GDPR, given the central authority's access to information.

Permissioned networks are also more vulnerable to 51% attacks if the central authority is compromised by an attacker.

Pitfalls

Blockchain suffers from a few problems which could hinder its implementation across the healthcare industry. Distributed ledgers, for example, are difficult to search which makes them impractical to use as information repositories for clinical and research purposes (OECD, 2020). This hindrance when deploying blockchain-enabled ledgers across the healthcare industry could impact the scalability of the technology. This limitation may be quickly overcome as blockchain becomes more widely adopted and technological fixes are developed.

A 51% attack is another risk that threatens the security and stability of a healthcare blockchain network. In this type of attack, an individual or group controls more than 50% of the node network, meaning they can verify, mutate, and add illegitimate blocks to the blockchain. Bitcoin suffered this type of attack in 2014, but these types of attacks are computationally challenging to carry out successfully (Bambrough, 2021). Bitcoin mining is currently concentrated between three large pooling companies, a feature that almost eliminates the decentralization aspect of the Bitcoin public network.

Blockchain in Healthcare

An OECD report on blockchain in healthcare emphasized the "newness" of the technology but provided no means of carrying out the implementation of this technology. There are numerous uses for blockchain in healthcare such as supply chain management, electronic health record-keeping, clinical trial data provenance, and smart contracts (Namasudra and Deka, 2020).

Supply Chain Management

There were over $200 billion of counterfeit drugs recorded out of $1,200 billion in drugs sold across the world in 2020. The United States accounted for about 49% of these figures. According to the World Health Organization, counterfeit drugs fail to "properly treat the disease or condition for which they were intended" and can lead to serious health consequences, including death. Despite regulations that limit the resale of returned drugs, it is estimated that 2% to 3% of drugs sold are returns, meaning there exists a 1/50 chance the products patients are buying are counterfeit (Howells, 2019).

Novartis and Merck have already been exploring the use of blockchain in their supply chain. They have incorporated the technology in the final stage of the supply chain to provide patients with accessible and updated electronic medical leaflets. When a patient scans the QR code on the packaging, the scan "recognizes the manufacturer and then sends a request for the most up-to-date digital leaflet" for that drug (Jennings 2021). The manufacturer must then be able to prove that the correct product information was provided to the patient through the blockchain ledger. This application of blockchain ensures that the patient is provided with the most accurate instructions for use. It also allows for them to quickly know whether or not the drug has been recalled, thereby preventing potential harm.

Patient Identity

A Serious Hazards of Transfusion (SHOT) Report from 2017 identified 115 episodes of error involving incorrect patient identification, 75% of which occurred in clinical trial settings. The Patient Safety Network compiled some instances of misidentification errors. In Event #1, a patient suffering from deep vein thrombosis (DVT) mistakenly received a computed tomography (CT) scan of her right upper extremity, rather than scans of the abdomen, pelvis, and head requested by the physician because it had been ordered for a patient with the same first name (Choudhury and Vu, 2020). Placing these types of requests on a verified blockchain would allow the CT technician to only complete the ordered scans after verifying the patient's identity via the blockchain.

In Event #2, two patients with similar head and face injuries in adjacent rooms received CT scans under the other patient's name. The emergency department (ED) team realized the physical assessments did not coincide with the CT scans and requested the results be correctly labeled. Such errors could have resulted in either patient receiving the wrong treatment, a dangerous and costly mistake. Misidentification problems also surface if data produced in two different settings are not in sync, a phenomenon known as patient matching. As a result, institutions have 20% of data as duplicates (Choudhury and Vu, 2020). This duplicity requires unnecessary storage and data resources, costing healthcare institutions. Placing immutable patient data and physician requests on a blockchain would allow the data to be verified, accepted, and validated by the network for reference, thereby eliminating the risk of associating a patient with inaccurate data.

There is a gateway problem associated with data integrity on the blockchain. If a practitioner or patient inputs the wrong information onto a blockchain transaction then the misidentification problem persists. Blockchain technology is designed to protect against the manipulation of data. It is often a given that data inputted onto the network must be reliable and accurate to begin with, otherwise, the blockchain network will promote the immutability of "garbage" data. This concept is known as data origin integrity. Oracles connect blockchains to real-world data they could not otherwise tap into. Such access allows blockchains to execute smart health insurance contracts that are dependent on third-party databases. The submission of data to the blockchain relies on oracle integrity. Blockchains are made of digital representations of real-world objects. Concerns include that digital representations on the blockchain may differ from the real world's current characteristics. This is referred to as digital twin integrity (World Economic Forum).

Blockchain's immutability does not necessarily address the gateway problem but allows for improved traceability meaning the origin of an error (often resulting from poor data) can be traced back with greater ease. Although a secure computer can upload data, the integrity of that data could still be compromised if, for example, the data was collected using a broken supply chain sensor. Ultimately, accuracy needs to be maintained from data creation to uploading on the blockchain to preserve the integrity of the network.

Clinical Trials

Over 50% of clinical trials and their corresponding data are never reported or published. This phenomenon places clinical trial participants at risk and replicates often similar trials thereby wasting money and clinical resources. Two notable examples of compromised clinical trials include Tamiflu, the popular flu medication, and Lorcainide, a drug used to help restore normal heart rhythm. Tamiflu provided the United Kingdom government with preliminary and arguably incomplete data. The drug subsequently received a five-hundred million pound subsidy before it was found to be statistically less effective than initially reported (Goldcare, 2014). Roche was found to have withheld clinical trial data. Regulatory agencies had difficulty in accessing the data during a subsequent review that showed a cause of abnormal behavior in children (i.e. hallucinations). The agencies concluded that the benefits did not outweigh the drug's risks.

Lorcainide's trial ended in 1980 but was revisited in 1993 by a group of researchers who found the drug resulted in the death of nine men versus one allocated the placebo. Although the trial in 1980 reflected the same issues, it was not properly disclosed which resulted in social and economic costs (Chalmers, 2021). Blockchain can play a critical role in preserving a trial's data provenance by ensuring trials do not go unpublished because they were unsuccessful or less favorable. Once data is placed on the blockchain, it is immutable unless a majority of the network decides to mutate it. Eliminating data manipulation or publishing bias via the immutable and transparent characteristics of blockchain will help alleviate these clinical trial problems. Having numerous authenticated validators such as pharmaceutical companies, regulators, and clinical trial participants on the blockchain would ensure data is properly added to the network.

Smart Contracts

Smart, or conditional, contracts are a preprogrammed set of instructions where the execution of the contract is triggered by certain predefined events. These contracts are particularly useful for processing insurance claims and provide numerous advantages over traditional agreements or contracts. Smart contracts are tamper-proof, require no human interaction, and can be automatically executed after a company receives data of a covered event.

Smart contracts would also allow for information to be standardized across the healthcare system, meaning patients would not have to update information at a new provider or hospital. A smart contract protocol could be used to execute a life insurance policy. Linking the contract to a government census database like the National Death Index (NDI) via an oracle would allow the claim to be paid out instantaneously upon the death of a policyholder. In this way, smart contracts in healthcare reduce latency and decrease the burden on the healthcare system and its users.

Estonia Case Study

Estonia is the most advanced nation with respect to blockchain implementation and has demonstrated the technology's great promise. The country's "e-Estonia" initiative has deployed blockchain technology across numerous categories including financial services, transportation, identity, education, and healthcare. In fact, Estonia became the first country to explore the use of blockchain on a national level for its healthcare system. Estonia now leads blockchain efforts and has been able to digitize 99% of its medical services information. It has developed a trackable e-Health record. The system leverages a blockchain architecture to keep information secure and accessible to authorized individuals.

Estonia utilizes the Keyless Signature Infrastructure (KSI) Blockchain and is designed in a way in which data never leaves the system, only a hash is sent to the blockchain. This design allows for greater scalability as the blockchain is capable of ensuring the immutability of petabytes of data. This technology is used by NATO and the United States Department of Defense which underscores the technology's safety, reliability, and scalability (Martinson, 2019). Estonia undertook this initiative to provide an additional layer of security for its citizens' health records. Estonia and other countries recognize that healthcare data provenance is a top priority for governments (e-Estonia, 2021). It is worth noting that Estonia's Social Health Insurance covers 95% of its population via the Estonian Health Insurance Fund. The centralized nature of this universal healthcare system makes the implementation of blockchain much more straightforward when compared to the United States' privatized system.

Existing Literature

Biplov (2020) and Lau (2018) provide robust analysis regarding the different features, advantages, and architectures of blockchain, however, they fail to quantify any meaningful advantage of the technology. Biplov highlights specific applications of blockchain in healthcare including data management, supply chain management, prescription management, claim and billing management, and medical research. Lau focuses on the use of different blockchain architectures (i.e. permissioned versus permissionless). They also explore different structures to optimize an electronic health record (EHR) system.

Khurshid et al (2021) more closely quantify the benefits of using a blockchain application. MediLinker is a patient-centric identity management system. Its decentralized identity architecture gives individuals greater autonomy over their information. The research team used a simulated set of "avatars" to represent a wide range of patients. Participants were then enrolled and asked to visit simulated clinics where they would perform a variety of relevant activities. These participants were then evaluated based on criteria for patient-centric identity management and the number of errors during the data entry and sharing process. This study shows there is a benefit to using blockchain technology as part of a patient-centric identity management system. Patients were able to use the system to validate their identity necessary to check-in at clinics, share personal information, withdraw permissions, and make changes to their personal data. Although the study does not compare performance before and after blockchain, it was able to highlight some of the benefits of blockchain. For example, 93% of participants had full control of their data and their EHR accounts were not compromised throughout the study (Khurshid et al, 2021).

Trigo (2020) focused on developing the best approach for supporting the traceability of healthcare data while finding a balance between decentralization and required computational power. They outline a prototype, called the iReceptor Plus, which will allow for the creation of data that can be tracked by other authorized entities. This, in turn, allows other entities on the blockchain to audit the data. Given the size of electronic health records, it is not feasible to have each node store the entire data set. Rather nodes are designed to have a pointer to the repository that allows for the retrieval of the information when needed. This prototype also implements a reward system that prioritizes good behavior on the network while penalizing bad behavior. This is paired with a PoS architecture to create a social credit incentive system instead of a cryptocurrency reward system (Trigo, 2020).

How

Blockchain data collection for this thesis proved to be more difficult than expected, a factor underscored by the lack of data in existing academic literature. This problem is just now being solved given recent blockchain-oriented studies and the formation of pilot programs. As these programs mature, we can expect there to be a greater level of data disclosure and studies concerning blockchain in healthcare.

Data

Finding data to conduct this research has been challenging given the recent adoption of blockchain in the healthcare industry. PharmaLedger was the most promising source of data as it is a pilot program with a consortium of companies, regulators, and institutions based in or operating in the European Union. This program deployed blockchain around March of 2021 and has been working to study the benefits of blockchain (PharmaLedger).

Data could also have been sourced from the University of Texas at Austin study and although the study was insightful, it provides only a superficial analysis of the benefits of blockchain technology. Expanding the scope of this data to include accuracy and efficiency in an environment without and with blockchain would help draw stronger conclusions. To meet the empirical component of this thesis, the paper pivoted to analyzing readily available stock data with respect to companies implementing and those not yet implementing blockchain. This thesis attempts to see the impacts of blockchain technology adoption on stock performance, the best proxy with available data for company efficiency.

Methodology

There is one concern regarding confounding variables: do companies who implement blockchain do so because they are already better performing and more efficient, meaning the improved efficiency is not truly attributable to the implementation of blockchain? To solve this problem, the methodology for analyzing data takes the form of a difference of differences analysis. This approach relies on the parallel trends assumption and observes the trajectory between companies that do not implement blockchain and those that do. By following the trends of both categories, we can then predict the trend into the post-treatment period and measure the intervention effect of blockchain. The intervention effect is the additional change to the constant difference in outcome.

The ideal experiment would consist of companies randomly implementing blockchain. A meaningful sample size of over 20 units over time would help underscore the validity of this estimation. The analysis in this paper mirrors that of a difference in differences but it does not fully implement the method given only two pairs of companies (CVS/Walgreens and McKesson/Cardinal Health). Standard errors in a DID analysis have been shown to understate the standard deviation of the estimated treatment effects. This causes an over-estimation of the t-statistics and significance levels (Bertrand et al, 2004). The DID approach uses the estimation equation below:

$$Y_{it} = B_0 + B_1 D_{it} + B_2 T_t + B_3 T_t D_{it} + \varepsilon_{it}$$

D_{it} is a dummy variable for the treated group that takes place between period 1 and period 2 for the companies

T_t is a time period dummy variable 0 in period 1 (pre-implementation), and 1 in period 2 (post-implementation)

The difference in outcomes, especially when conducted on a larger sample of companies, could help show managers and investors how implementing blockchain can have a positive impact on returns. This paper discusses how inefficiencies resolved by blockchain can impact cash flow, a metric that plays a role in stock performance since it encompasses the firm's operating performance and exercise of real options (Jansen, 2021). Of course company culture, strategic initiatives, and market disruptions like COVID could impact these returns. The analysis would have to show that the adoption of blockchain is not simultaneous with a change in corporate strategy. Analyzing pre trends could help validate whether the effects are causal. If, for example, there are no pretrends, then the effect is likely causal.

The DID analysis relies on the parallel trends assumption to observe pre and post-treatment differences. The assumption states that treatment and comparison groups should have the same pre-treatment outcome, but can have different outcomes after the treatment. Furthermore, common shocks are often grouped under the parallel trends assumptions since it is the idea that “shocks”, like COVID-19, have the same effect on both groups.

Difference in Differences

The analysis currently focuses on two pairs of comparable companies, CVS, which has been using blockchain since March of 2019, and Walgreens which is not yet using blockchain. McKesson also started using blockchain in June of 2019, while Cardinal Health has only explored the use of the technology. The red lines in the graphs below show the date of implementation for the two pairs of stocks. Upon initial examination, there seems to be a clear intervention effect in stock performance after the implementation of blockchain. The size of the intervention effect will become much clearer, after conducting a difference in differences analysis. Returns in the difference in difference analysis were calculated monthly over a 5-year (60-month) period.

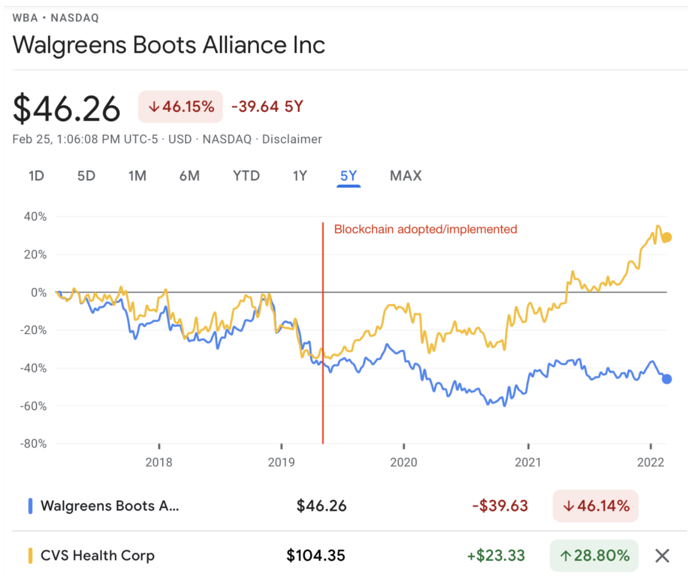
Steps of Analysis

The Python analysis makes use of the statsmodels module that contains an ordinary least squares function, as well as the pandas and numpy modules necessary for conducting the DID analysis. The following list outlines the general steps used for building the statistical model and Appendix 1 contains the code for running this analysis:

1. Defining a file path to the company pair return data
2. Dropping any unnecessary columns
3. Cleaning the return columns to convert them from strings to numeric (float64) types
4. Setting the index as both Date and Company for easier manipulation of the data
5. Created a treatment column with a default value as 0
    a. Set anything after the implementation date in the treated column to 1
6. Added an "is_cvs" and "is_mck" column as a binary variable to identify the treatment group for each pair analysis, respectively
7. Used the following model: *model = 'ret ~ is_cvs + treated + treated * is_cvs'*
    a. Where *ret* is returns
    b. *is_cvs* (*is_mck* in the McKesson and Cardinal Health pair) is a binary variable column to determine whether it is the treated company
    c. and *treated* is whether or not it is pre or post-treatment
8. Ran and fit the ordinary least squares (OLS) regression

Pairs of Companies

CVS (implemented blockchain ~ March 2019) versus Walgreens (not yet using blockchain):



McKesson (started using blockchain in June of 2019) versus Cardinal Health (still exploring the use of blockchain):

Two python notebooks were created, one for each pair of companies, using Jupyter Notebook. The code implementation is identical for both pairs with the only difference being the implementation date that varies between both pairs. The first pair consists of Walgreens and CVS, both large American-based pharmacies. CVS implemented blockchain technology in March of 2019 (Landi, 2019). The second pair was McKesson and Cardinal Health, two large multinational healthcare distributors. McKesson chose to implement blockchain in June of 2019 (Miliard, 2019). Each pair of companies operate in similar businesses which helps eliminate the need to control for variables like varying business models. Upon initial examination of the pairs' cumulative returns, CVS and McKesson appear to experience substantial stock returns after implementing blockchain technology. The DID analysis looks at the change in stock returns, or performance, before and after the implementation of blockchain. Expanding the set of companies using and not using blockchain in a future study would help improve the validity of the difference in differences analysis. Ideally, about 15 companies using blockchain and 15 companies not using blockchain would help provide a more robust dataset for analysis between the control and treatment groups.

An important consideration of this analysis is that a change in corporate strategy, which also would likely impact stock performance, cannot coincide with the implementation of blockchain. A custom date range Google search shows no news of changing corporate strategy for any company 2 months prior to and following the implementation of blockchain. A news search for "cvs health corporate strategy" and "walgreens corporate strategy" between January 1, 2019, and May 31, 2019, showed no relevant results regarding a change in corporate strategy. A search for "mckesson corporate strategy" and "cardinal health corporate strategy" between April

1, 2019, and August 31, 2019, produced similar results. Eliminating the possible impact of these types of variables is important for interpreting the analysis' p-values.

Findings, Takeaways, and Where the Companies Are Now

The CVS Health and Walgreens DID analysis produced a p-value of 0.336 and a coefficient of 0.0305 or 3.05% shown in Table 1. The coefficient seems to show that there is a significant difference in stock performance between CVS (using blockchain) and Walgreens (not using blockchain). The higher than desired p-value, however, clouds the impact of blockchain on stock returns. Similarly, the McKesson and Cardinal Health DID analysis produced a p-value of 0.400 and a coefficient of 0.0307 or 3.07% also shown in Table 1. The companies using blockchain certainly appear to outperform their non-blockchain competitors. The coefficient in both analyses could indicate that there is a link between using blockchain and stock performance, however, the non statistically significant p-value muddies whether or not there is a direct impact.

This report is a preliminary approach to analyzing the quantitative impact of blockchain. As new pairs of companies become available, they will be able to help strengthen the validity of the current p-values and coefficients. We can conclude that using stock performance as a proxy for company efficiency is a good indicator of the effects occurring after the implementation of blockchain. Ultimately, blockchain technology is a means of reducing errors which translates into improved profitability. Blockchain's role in reducing script, patient identity, and chargeback errors also helps reduce mortality, thereby underscoring the social use case for blockchain. The aforementioned results are outlined in Table 1 below:

Table 1: Returns by Company Pair

Dependent Variable:	Pharmacy Returns	Distributor Returns
	(1)	(2)
Post Implementation of Blockchain	0.336	0.400
Observations	118	118
Coefficient	0.0305	0.0307

Note: This table shows the effect of the implementation of blockchain on the returns for two pairs of companies in the healthcare industry. Pharmacy Returns refers to the CVS and Walgreens pair whereas Distributor Returns refers to the McKesson and Cardinal Health pair. Neither p-value demonstrates a meaningful level of statistical significance (i.e. below 0.1 or 0.05).

CVS adopted blockchain technology to promote accurate prescription scripts, efficient claims, and optimized payment processing. This would allow for streamlined information exchange in the healthcare industry and maintain accurate directories. CVS' and Aetna's (owned by CVS) aim was to prioritize accuracy, security, and sharing capabilities on an inclusive network. As of mid to late 2021, CVS committed $3 billion to technology initiatives. The continued investment is a signal that the pilot trial was a successful first phase. Karen Lynch, CVS Health's president, and CEO emphasized that the firm's technology programs have continued to use blockchain to drive cloud migration, automation, and streamline processes. CVS has continued pursuing blockchain-driven technologies to also improve customer experience (Grill-Goodman, 2021).

The use of blockchain to counter inefficient processing is welcome news as an audit of CVS found an error rate of 22% or 66 out of 305 prescriptions. When these errors are severe, they result in costly fines, sometimes exceeding $125,000 (Gabler, 2020). Blockchain's ability to mitigate these types of errors would reduce CVS' fines, thereby improving the firm's profitability. This reduction in fines is a factor that can likely be reflected in the firm's stock performance. CVS recognizes that digital retail customers have longer lifetime value, manage more scripts, and spend two and a half times more in the storefront meaning investments in digital initiatives are an utmost priority for the company.

McKesson partnered with Chronicled, the custodian for the MediLedger Network, to join the pilot program. McKesson's use of blockchain is focused on reducing the complexity of procurement systems resulting from pricing errors that cause re-billing. McKesson worked with Chronicled to improve pricing quality and trading partner alignment, two areas that would reduce chargeback errors. Mediledger's blockchain network focuses on real-time alignment, rule enforcement, and settlement of transactions between partners. This allows Mediledger to verify group purchasing organization (GPO) rosters using integrated data and to automate membership management protocols.

McKesson found the healthcare industry wastes $500mm to disputes and inefficiencies between partners. McKesson, along with Chronicled, estimated that the system would reduce errors on the MediLedger network by 98%. Another objective was to decrease the industry average chargeback and billing error rate from 4% to under 0.1%. These chargeback and billing errors often directly link to cash flow which hinders financial performance and impacts stock returns. MediLedger acts as a centralized source of truth that updates data when a hospital joins or leaves a group purchasing organization. If the wholesaler or manufacturer then changes the contract terms, all GPO members will have access to the change which allows for accurate up-to-date pricing, thereby reducing pricing errors (Parity Technologies, 2022). McKesson is still involved in the MediLedger program which continues to attract new firms like Pfizer, Bayer, and AmerisourceBergen (Miliard, 2019). McKesson is also involved in the 340B landscape which has expanded its presence in the Medileger program from 1,200 to 28,000 participants further underscoring the success of this pilot program. Interoperability between firms will produce positive network effects that further the reduction in errors.

Generalizations

This study could help guide analysis in future industries relying heavily on data management, supply chain management, and data provenance. It also provides a framework for approaching studies with little to no directly available data and those suffering from confounding variables. Other applications could include analyzing the implementation of blockchain for companies in aerospace, industrial, and agricultural settings. This methodology could also be helpful in analyzing the impact of a technological adoption by a group of companies.

Conclusion

Although difficult to quantify, blockchain can improve supply chain security, electronic health records accuracy, billing and claims management, and clinical trial data. Blockchain allows companies like CVS and McKesson to correct costly inefficiencies, thereby leading to improved cash flows and better financial performance. The DID approach appears to show a different, higher return for companies that adopted blockchain vis-a-vis comparable companies not yet using the technology. Therefore, companies appear to have a financial incentive to adopt blockchain. This approach provides a means for analyzing companies' stock performance ex-ante and ex-post the implementation of blockchain in the treated company. Future iterations of this study will rely heavily on expanded data sets as more companies begin to adopt blockchain.

I would like to use this space to emphasize the importance of data availability. Protecting the competitive advantages of companies should be of utmost importance, but it should not inhibit access to data that can help the broader industry. Blockchain has clear theoretical advantages over current systems in the healthcare industry, but the lack of data makes it difficult to verify. The United Kingdom, for example, has implemented open banking, a system that "connects banks, third-parties and technical providers – enabling them to simply and securely exchange data to their customers' benefit". The United States should follow suit, making blockchain healthcare data available so that it can be more easily studied.

Works Cited

"An Approach To Contract Alignment and Chargebacks | Prescribed Perspectives." *McKesson*, McKesson Corporation, https://www.mckesson.com/Pharmacy-Management/Health-Systems/Prescribed-Perspectives/Contract-Alignment-and-Chargebacks/.

Bambrough, Billy. "Bitcoin Fork Suffers 'Massive' 51% Attack in Attempt to 'Destroy' the Cryptocurrency, Sending Its Price Sharply Lower." *Forbes*, Forbes Magazine, 4 Aug. 2021, https://www.forbes.com/sites/billybambrough/2021/08/04/bitcoin-fork-suffers-massive-51-attack-in-attempt-to-destroy-the-cryptocurrency-sending-its-price-sharply-lower/?sh=3ce30932248f.

Biplov, K.C., et al. "Blockchain in Healthcare." *University of Koblenz-Landau*, University of Koblenz-Landau.

"Blockchain and Healthcare: The Estonian Experience - e-Estonia." *e-Estonia*, Enterprise Estonia, 13 June 2018, https://e-estonia.com/blockchain-healthcare-estonian-experience/.

"Blockchain Healthcare and Life Sciences Solutions." *IBM*, https://www.ibm.com/blockchain/industries/healthcare.

Chalmers, Iain. "The True Lorcainide Story Revealed." *The BMJ*, BMJ Publishing Group Ltd, 14 Dec. 2021, https://www.bmj.com/content/350/bmj.g7717/rr-1.

Choudhury, Lamia S, and Catherine T Vu. "Patient Identification Errors: A Systems Challenge." *Patient Safety Network*, Agency for Healthcare Research and Quality, 29 Jan. 2020, https://psnet.ahrq.gov/web-mm/patient-identification-errors-systems-challenge.

“Data Integrity.” *World Economic Forum*, World Economic Forum, https://widgets.weforum.org/blockchain-toolkit/data-integrity/index.html.

Dawson, Rob, and Meredith Baxter. “Announcing Hyperledger Besu.” *Hyperledger Foundation*, The Linux Foundation, 29 Aug. 2019, https://www.hyperledger.org/blog/2019/08/29/announcing-hyperledger-besu.

El-Gazzar, Rania, and Karen Stendal. “Blockchain in Health Care: Hope or Hype?” *Journal of Medical Internet Research*, JMIR Publications, 10 July 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7382018/.

Ferguson, Caleb, et al. “The Wicked Problem of Patient Misidentification: How Could the Technological Revolution Help Address Patient Safety?” *Wiley Online Library*, John Wiley & Sons, Ltd, 1 Apr. 2019, https://onlinelibrary.wiley.com/doi/full/10.1111/jocn.14848.

Filipe da Silva Trigo, Dinis. “Blockchain-Based Approach for Sharing Health Research Data.” University of Porto, 23 July 2020. https://repositorio-aberto.up.pt/bitstream/10216/129072/2/416536.pdf

“The Future of Financial Services.” *Open Banking*, Open Banking Limited, 3 May 2022, https://www.openbanking.org.uk/.

Gabler, Ellen. “CVS Fined for Prescription Errors and Poor Staffing at Pharmacies.” *The New York Times*, The New York Times Company, 16 July 2020, https://www.nytimes.com/2020/07/16/business/cvs-pharmacies-oklahoma.html.

Goldcare, Ben. “What the Tamiflu Saga Tells Us about Drug Trials and Big Pharma.” *The Guardian*, Guardian News and Media, 10 Apr. 2014, https://www.theguardian.com/business/2014/apr/10/tamiflu-saga-drug-trials-big-pharma.

Grill-Goodman, Jamie. “CVS Health Investing Up To $3 Billion In Tech and Growth, Raises Wages.” *RIS News*, EnsembleIQ, 8 Dec. 2021, https://risnews.com/cvs-health-investing-3-billion-tech-and-growth-raises-wages.

“Healthcare.” *e-Estonia*, Enterprise Estonia, 15 Nov. 2021, https://e-estonia.com/solutions/healthcare/e-health-records/.

Howells, Richard. “Counterfeit Drugs: A Bitter Pill to Swallow.” *Forbes*, Forbes Magazine, 18 Oct. 2019, https://www.forbes.com/sites/sap/2019/10/03/counterfeit-drugs-a-bitter-pill-to-swallow/?sh=7e1df4e37a68.

Jansen, Benjamin A. “Cash Flow Growth and Stock Returns.” Middle Tennessee State University, 19 Jan. 2021. https://onlinelibrary.wiley.com/doi/epdf/10.1111/jfir.12244

Jennings, Katie. “Pharma's Blockchain Trials: Novartis, Merck Test the Tech Popularized by Bitcoin.” *Forbes*, Forbes Magazine, 2 Feb. 2021, https://www.forbes.com/sites/katiejennings/2021/02/02/pharmas-blockchain-trials-novartis-merck-test-the-tech-popularized-by-bitcoin/?sh=5659948b7e86.

Khurshid, Anjum, et al. Oxford University Press, Austin, Texas, 2021, *Designing and Testing a Blockchain Application for Patient Identity Management in Healthcare*.

Landi, Heather. “Aetna, IBM Launching New Blockchain Healthcare Network.” *Fierce Healthcare*, Questex LLC, 28 Jan. 2019, https://www.fiercehealthcare.com/tech/aetna-anthem-hcsc-and-ibm-creating-new-blockchain-healthcare-network.

Lau, Erik, et al. “Decoding the Hype: Blockchain in Healthcare.” *Utrecht University*, Utrecht University, 2018.

Martinson, Priit. “Estonia – the Digital Republic Secured by Blockchain.” Aktsiaselts PricewaterhouseCoopers, 2019. https://www.pwc.com/gx/en/services/legal/tech/assets/estonia-the-digital-republic-secured-by-blockchain.pdf

Materese, Robin. “Blockchain.” *NIST*, National Institute of Standards and Technology, 4 Jan. 2022, https://www.nist.gov/blockchain.

“The Mediledger Network.” *The MediLedger Network*, https://www.mediledger.com/#Live-Solutions.

Miliard, Mike. “Premier, Pfizer, McKesson, Others Join Blockchain Working Group.” *Healthcare IT News*, HIMSS Media, 3 May 2019, https://www.healthcareitnews.com/news/premier-pfizer-mckesson-others-join-blockchain-working-group.

Nakamoto, Satoshi. “Bitcoin: A Peer-to-Peer Electronic Cash System.” https://bitcoin.org/bitcoin.pdf

Namasudra, Suyel, and Ganesh Chandra Deka, editors. *Applications of Blockchain in Healthcare*. Singapore : Springer, 2021. https://bobcat.library.nyu.edu/permalink/f/ci13eu/nyu_aleph008316746

“Opportunities and Challenges of Blockchain Technologies in Health Care.” Secretary-General of the OECD, Dec. 2020. https://www.oecd.org/finance/Opportunities-and-Challenges-of-Blockchain-Technologies-in-Health-Care.pdf

“Parity Technologies and MediLedger Network Announce Partnership to Deliver Blockchain-Powered Solutions to the Life Sciences Industry.” *PR Newswire*, Cision US

Inc., 21 Jan. 2022, https://www.prnewswire.com/news-releases/parity-technologies-and-mediledger-network-announce-partnership-to-deliver-blockchain-powered-solutions-to-the-life-sciences-industry-301465714.html.

"Pharmaledger." *PharmaLedger*, 2021, https://pharmaledger.eu/.

Shi, Shuyun, et al. "Applications of Blockchain in Ensuring the Security and Privacy of Electronic Health Record Systems: A Survey." *Computers & Security*, Elsevier Ltd., Oct. 2020, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7362828/.

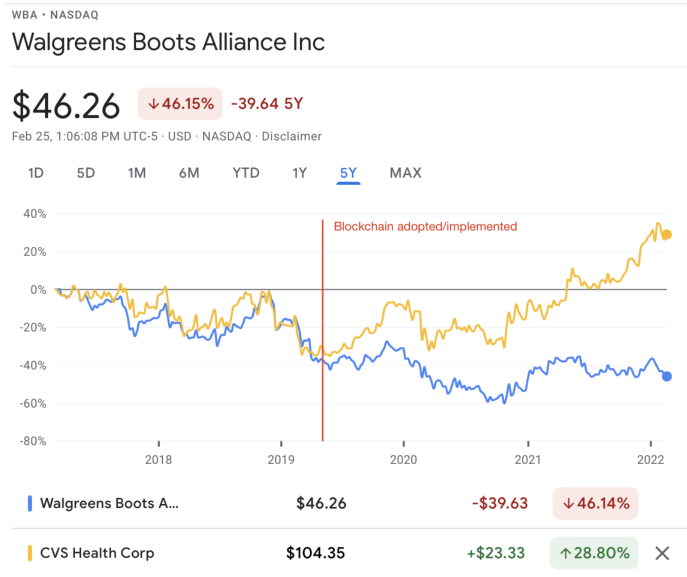
Appendix

Appendix 1

```
import pandas as pd
import statsmodels.formula.api as smf
import numpy as np

path = '/Users/jonpaullambert/Desktop/NYU/Stern Honors
Thesis/DID/CVS and WAB/CVS_WBA.csv'

df = pd.read_csv(path)

df = df.drop(['Unnamed: 5', 'Unnamed: 8', 'Unnamed: 9',
'Pre', 'Post'], axis=1)

df = df.iloc[1:]

df['WBA Return'] = pd.to_numeric(df['WBA
Return'].str.replace('%', ''))/100

df['CVS Return'] = pd.to_numeric(df['CVS
Return'].str.replace('%', ''))/100

df['Date'] = pd.to_datetime(df['Date'])

df.dtypes

wba = pd.Series(df['WBA Cumulative Return'])
cvs = pd.Series(df['CVSS Cumulative Return'])
wba.plot()
cvs.plot()

returns = df[['Date', 'WBA Return', 'CVS Return']]
returns.head()

returns = returns.rename(columns={"WBA Return": "wba", "CVS
Return": "cvs"})
wba = returns[['Date', 'wba']]
cvs = returns[['Date', 'cvs']]

wba = wba.copy()
wba = wba.rename(columns={'wba': 'ret'})
wba['company'] = 'wba'

cvs = cvs.copy()
cvs = cvs.rename(columns={'cvs': 'ret'})
```

```
cvs['company'] = 'cvs'

returns = wba.append(cvs)
returns.head()
returns.set_index(['Date', 'company']).unstack('company')

both = returns.set_index(['Date',
'company']).unstack('company')
both.head()

both['treated'] = 0
both['treated'] =
both.treated.where(both.index<'2019-03-01', 1)
both.head()

returns.head()

returns['treated'] = 0
returns['treated'] =
returns.treated.where(returns.Date<'2019-03-01', 1)
returns.head()

returns['is_cvs'] = np.where(returns.company == 'cvs', 1,
0)

returns.head()

returns

model = 'ret ~ is_cvs + treated + treated * is_cvs'

mod = smf.ols(formula=model, data=returns)
res = mod.fit()
print(res.summary())
```

Appendix 2



Appendix 3

Appendix 4

Dependent Variable:	Pharmacy Returns	Distributor Returns
	(1)	(2)
Post Implementation of Blockchain	0.336	0.400
Observations	118	118
Coefficient	0.0305	0.0307