Blockchain Adoption and Investment Efficiency

Tzu-Ting Chiu
Norwegian School of Economics
tzu-ting.chiu@nhh.no

Jee-Hae Lim
University of Hawaii at Manoa
jeehae@hawaii.edu

Simone Traini
Norwegian School of Economics
simone.traini@nhh.no

Abstract

This study empirically examines the relation between blockchain adoption and investment efficiency. Using a difference-in-differences approach with a sample of U.S. listed firms that indicate adoption of blockchain in business processes in 8-K filings during 2014 to 2019, we find that relative to non-adopters, blockchain adopters exhibit increased investment efficiency (as reflected in higher investment-price sensitivity) after adoption. We further find that only firms with poor information environments experience increased investment efficiency following blockchain adoption. These results suggest that potential improvements in firms' overall information transparency and quality could be a channel through which blockchain adoption enhances investment efficiency.

Keywords: blockchain; information environment; investment efficiency; investment-price sensitivity.

1. Introduction

This study examines whether and how a firm's adoption of blockchain technology in business processes affects investment efficiency. Blockchain is a form of distributed ledger technology. It records and verifies transactions instantly in a cryptographically secure system with continuously growing blocks, which protects data immutability and provides verified real-time information among network users. Blockchain features strong security, record integrity, disintermediation, and automation of transactions (Chod et al. 2020). Due to these features, blockchain can help improve trust, speed, and efficiency and reduce transaction costs, which makes blockchain adoption appealing to firms (Fanning and Centers 2016, Dai and Vasarhelyi 2017, Gomber et al. 2018, Gaur and Gaiha 2020).[1] According to Research and Markets, a leading provider of market research, blockchain spending in the U.S. has increased drastically and will be over $41 billion by 2025.[2] Gartner forecasts that blockchain technology will create more than 176 billion dollars' worth of business value by 2025 and $3.1 trillion by 2030, highlighting the economic importance of blockchain.[3]

Blockchain is considered as one of the most valuable FinTech innovations and has been applied by firms in various industries (Chen et al. 2019).[4] Nevertheless, some firms are still hesitant to adopt this technology due to concerns about lacking clear standards and regulations as well as uncertainties about costs and benefits (Deloitte 2021). Blockchain adoption requires a significant commitment of resources, but the return on blockchain investment is uncertain, depending on a firm's market position and specific use cases (Carson et al. 2018). Besides the investment cost, blockchain adoption comes at a cost of sharing proprietary information with network users (Yermack 2017, Cong and He 2019, Guo et al. 2021). Therefore, it is important for firms to assess potential costs and benefits carefully when deciding whether to adopt blockchain in their businesses.

Improved efficiency is perceived as one of the major benefits from using blockchain. Carson et al. (2018), among others, argue the impact of blockchain application on improving operational efficiency, and Cao et al. (2019) discuss the use of blockchain in enhancing audit efficiency. However, there is limited empirical evidence on the effects of blockchain adoption on various efficiencies in the growing literature on blockchain. In addition, given mixed evidence documented by recent research on stock

[1] Note that the benefits of blockchain will depend on the type of blockchain used, i.e., whether it is public or private, permissionless or permissioned. For example, there is a possibility of collusion among network users under permissioned private blockchain, which could lead to data being tampered or manipulated (Cong and He 2019).

[2] https://www.globenewswire.com/news-release/2019/03/25/1760459/0/en/Blockchain-in-the-United-States-Forecast-to-2025-Spend-on-Blockchain-is-Expected-to-Record-a-CAGR-of-44-5-Increasing-from-3-12Bn-in-2019-to-41-11Bn-by-2025.html

[3] https://www.gartner.com/en/doc/3855708-digital-disruption-profile-blockchains-radical-promise-spans-business-and-society

[4] See Section 2.1 for the discussion of Walmart's use of blockchain in its business operations.

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market reactions to firms' blockchain announcements, it is unclear whether blockchain adoption creates value from investors' views (Cheng et al. 2019, Cahill et al. 2020, Autore et al. 2021b).

In this study, we focus on the effect of blockchain adoption on firms' investment efficiency. We posit that adopting blockchain technology in business processes can help firms achieve greater investment efficiency for the following reasons. First, blockchain could enhance the quality of information and the overall information transparency in business processes. Because of the immutability and real-time features, blockchain protects data integrity and offers instant access to synchronized data among network users (which thereby improves data visibility). Anecdotal evidence from a survey by Forrester Consulting in 2020 shows that around three-quarters of the surveyed blockchain users have experienced improvements in data quality, integrity, and visibility as a result of using blockchain in their supply chain.[5] Mangers would be able to allocate resources better and make more informed investment decisions when they are provided with more accurate, reliable, and timely information, thereby improving their investment efficiency. As demonstrated by Lambert et al. (2007), information quality can affect firms' real decisions. Second, real-time accounting afforded by blockchain provides firms with less opportunities and incentives to manage earnings, which could improve the quality of accounting information as well as reduce firms' engagement in value-destroying investment activities (Yermack 2017). Biddle and Hilary (2006) find that higher quality accounting information increases firms' investment efficiency by reducing information asymmetries between firms and investors.

Using a difference-in-differences approach with a sample of U.S. listed firms that indicate adoption of blockchain technology in 8-K filings during 2014 to 2019 versus firms that do not adopt blockchain, we find that blockchain adopters have higher investment-price sensitivity after adopting blockchain than non-adopters. Specifically, the investment-price sensitivity is 2.9 percentage points higher for blockchain adopters after adoption compared to non-adopters. This suggests that firms experience improvements in investment efficiency after adopting blockchain technology in their business processes. Our findings are robust to using an entropy balanced sample and a propensity score matched sample, which helps mitigate endogeneity concerns.

We perform several additional analyses to corroborate our findings. First, we explore variations in the stage of investment in blockchain technology and see how the impact on investment efficiency varies with different stages. We expect and find that only firms that are in a more advanced stage (i.e., beyond the R&D phase) exhibit higher investment efficiency after blockchain adoption. Second, to rule out reverse causality, we analyze the dynamic effects of blockchain adoption and find that increased investment efficiency appears only in the year of and the year after blockchain adoption but not in the year before adoption. Third, we further validate our main results by performing falsification tests using speculative blockchain adopters and a pseudo adoption year, respectively. We do not find an increase in investment efficiency following blockchain adoption when using a sample of speculative blockchain adopters and a pseudo adoption year. Fourth, to address self-selection bias, we run a Heckman two-stage model and obtain robust results. Fifth, to mitigate concerns of omitted variables, we additionally control for size, cash flow, leverage, cash holdings, and firm age. Our results hold after controlling for these variables. Lastly, to mitigate concerns that results are driven by certain types of investment, we use alternative measures of investment and find similar results.

Our study contributes to the literature in the following ways. First, we contribute to the emerging literature on blockchain (e.g., Biais et al. 2019, Cao et al. 2019, Cheng et al. 2019, Cong and He 2019, Chod et al. 2020) by providing one of the first empirical evidence on the real effects of blockchain adoption. Determining an appropriate level of spending on information technology (IT) could be challenging for managers given the uncertainty of return on IT spending and the high cost of IT investment (Ross and Weill 2002). Benefits must outweigh the costs in order to justify the adoption of blockchain technology and its spending. To our knowledge, our study is the first to provide systematic empirical evidence on whether and how blockchain adoption creates value to businesses by documenting the effects on firms' investment efficiency. Our findings lend support to the argument of value creation from using blockchain technology (e.g., Autore et al. 2021b).

Second, our study complements the existing research that examines the economics of blockchain adoption (e.g., Iyengar et al. 2021) by showing which firms could benefit most from adopting blockchain in their business processes. Our cross-sectional results reveal that the positive effects of blockchain adoption on investment efficiency only appear in firms with

[5] The survey findings are available at https://www.ibm.com/downloads/cas/JX9KDGPJ

weak information environments. This suggests that blockchain adoption potentially improves firms' overall information transparency and quality and thereby benefits firms with weak information environments the most. In other words, blockchain adoption is likely to create incremental value to these firms as it could facilitate managers' resource management and decision making, which in turn increases their investment efficiency.

Lastly, our paper adds to the literature that examines the sensitivity of corporate investments to stock prices (Chen et al. 2007, Foucault and Frésard 2012, Edmans et al. 2017, among others) by documenting how a firm's investment-price sensitivity changes as a result of blockchain adoption. According to the literature on managerial learning from prices (see Bond et al. 2012 for a review of this literature), stock price provides information that managers may not have because it aggregates news and signals from various market participants, which can guide managers in making corporate (e.g., investment) decisions. Stock price reactions to firms' blockchain news documented by recent research (e.g., Cheng et al. 2019) indicate that investors indeed react to and trade on such news, which might affect stock price informativeness and hence investment efficiency (as captured by the investment-price sensitivity). Taken together, our findings imply that blockchain adoption potentially increases price informativeness by improving information quality, which in turn affects investment efficiency.

2. Relevant Literature

2.1. Background

Blockchain is an innovative cryptography and information technology, considered to be one of the most valuable FinTech innovations. In particular, Chen et al. (2019) calculate and show that blockchain technology has a median value impact of $8.1 billion (2017 dollars) for the entire financial sector. In addition, a survey by the World Economic Forum in 2015 indicates that 10 percent of global GDP will be stored on blockchain by 2027.[6] This highlights the economic importance of blockchain among all recently developed technologies.

Blockchain presents an alternative of distributed ledgers to traditional financial ledgers, which could affect financial reporting by replacing double-entry bookkeeping (Yermack 2017). It allows entities to record transactions on a decentralized network, where all information is cryptographically secure and verified instantly, which prevents data from being altered ex post and hence protects data integrity. Blockchain technology helps improve interaction and collaboration between various parties with a shared source of trust by allowing them to access to the data and receive updates in real time, which could ultimately revolutionize many business products and processes.

Dai and Vasarhelyi (2017) discuss how blockchain can potentially afford a real-time, verifiable, and transparent accounting ecosystem. In an interview with *Financial Executives International Daily*, Jake Benson, CEO of Libra, a New York startup building front-end reporting software based on blockchain, said that "[Blockchain] is going to be more inherently trustworthy, it is going to be more accurate. Maybe you will get those [numbers] at a more frequent pace. … You will have increased transparency, increased frequency of date of delivery. I think they will just generally be more real-time."[7] Similarly, according to Campbell Harvey, Professor of Finance at Duke University's Fuqua School of Business, the primary benefit of blockchain to financial statements can be summed up in one term — real time (FEI 2017).

Advantages of blockchain technology include (1) strong security, (2) disintermediation, (3) record integrity, and (4) automation, which can help reduce the need for costly intermediaries, likelihood of fraud, and process inefficiency (Chod et al. 2020). Due to these advantages, blockchain has expanded its technical foundation to support various industries and fields since the introduction by Nakamoto (2008). Stratopoulos et al. (2021) provide evidence from corporate disclosures showing that the focus of blockchain adoption has shifted from Bitcoin and other cryptocurrencies to applications of blockchain in business processes in recent years. For example, Walmart Canada has successfully built a blockchain network to solve problems related to invoices from and payments to its 70 third-party freight carriers. The case study of Walmart Canada by Vitasek et al. (2022) offers insights on how to use blockchain technology for improving business processes, such as minimizing data discrepancies, which in turn can increase efficiency of operations.[8]

[6] A full report of the survey is available at https://www.weforum.org/reports/deep-shift-technology-tipping-points-and-societal-impact

[7] Interview video and transcripts are available at https://daily.financialexecutives.org/financial-reportings-logical-next-step-blockchain/

[8] Vitasek et al. (2022) describe that "With over 200 data points that needed to be factored into invoices, it is easy to see how the invoice

In a global blockchain survey by Deloitte (2021), most respondents believe that they can gain a competitive advantage and develop new revenue streams through blockchain applications. Despite the benefits that blockchain potentially offers, some firms are still hesitant to adopt blockchain due to security and regulatory concerns. Specifically, in the survey, respondents point out several areas where regulations need to be modified to facilitate blockchain adoption, including data security and privacy, industry-specific regulatory issues (e.g., FDA), geography-specific regulations (e.g., EU Data Protection Directive), and internal controls and financial reporting. Information distribution may trigger privacy and security concerns if anonymous users can access sensitive information (Cong and He 2019). After all, as Kumar et al. (2020) state, blockchain technology is not a silver bullet for all businesses; instead, it should be applied selectively on a case-by-case basis. Simply adopting blockchain does not guarantee a sustained competitive advantage.

Considering the investment cost and the accompanying cost of proprietary information sharing within the network, it is unclear whether the adoption of blockchain creates sufficient returns and benefits to businesses. Guo et al. (2021) find that early blockchain adopters experience lower returns on assets and operating cash flow and argue that adopting blockchain could be a lengthy and costly process. Real effects of blockchain adoption remain underexplored empirically in the growing literature on blockchain. By examining whether and how blockchain adoption relates to firms' investment efficiency, our study attempts to shed light on the real effect and a perceived benefit of blockchain — improved efficiency.

2.2. Hypothesis Development

Gaur and Gaiha (2020) argue that blockchain can improve trust, speed, and efficiency "by creating a complete, transparent, tamperproof history of the information flows, inventory flows, and financial flows in transactions." As evidenced by the anecdote of Walmart Canada, adopting blockchain in business processes helps minimize data discrepancies (and accompanying reconciliation efforts) and provides real-time information, which enhances the overall information transparency in business processes and the quality of information for managerial decision making. With timely, accurate, and reliable information, managers are likely to manage resources better and make better informed decisions, thereby improving their investment efficiency.

Further, real-time accounting and reporting afforded by blockchain could reduce managers' incentives to distort investment policies to manipulate reported earnings (FEI 2017, Yermack 2017). Because of real-time accounting and reporting, it would reduce firms' incentives to manage short-term (e.g., quarterly) earnings, which would also reduce incentives to engage in accounting gimmicks and value-destroying investment activities. A survey by Graham et al. (2006) indicates that managers are willing to sacrifice long-term value (e.g., by making suboptimal investment decisions) to meet short-term earnings targets. Consistently, Kraft et al. (2018) document a negative relation between financial reporting frequency and the level of investment in U.S. firms, suggesting that increased financial reporting frequency could induce managerial myopia and short-termism.[9] With real-time accounting and reporting, firms would be more incentivized to manage their resources and expertise better to increase firm value than to manage earnings to meet investors' and analysts' expectations, reducing the likelihood of value-decreasing actions and investments.[10]

Although blockchain technology can improve information accuracy and integrity, such as preventing managers from backdating sales contracts or capitalizing expenditures that should be expensed as incurred, it has limited ability to authenticate certain

and payment process could be fraught with data discrepancies. … Consequently, reconciliation had to be performed manually — a labor-intensive, time-consuming process riddled with inconsistencies." By using a blockchain network, "The system continuously gathers information at every step — from the tender offer from the carrier to the proof of delivery and the approval of payment. This information is automatically captured and synchronized in real-time and is visible only to the parties involved in the transaction. By all accounts the system has been a tremendous success. Prior to DL Freight over 70% of invoices were disputed. Today less than 1% of invoices have discrepancies, and these disputes are easily flagged and quickly resolved."

[9] In contrast, using a sample of U.K. firms, Nallareddy et al. (2021) find no impact of mandatory quarterly reporting on firms' investment decisions.

[10] Two recent papers examine the effects of blockchain adoption on firms' earnings management and document empirical evidence inconsistent with the belief that real-time accounting can help reduce firms' accrual earnings management. In particular, El Diri et al. (2021) find a higher level of accrual earnings management for blockchain adopting firms than for non-adopting firms, but they do not find an association between a firm's blockchain adoption and the level of real earnings management. Similarly, in a supply chain setting, Autore et al. (2021a) document that supplier firms' discretionary accruals increase and abnormal discretionary expenses decrease after their customers adopt blockchain, indicating an increase in accrual and real earnings management by supplier firms following customers' blockchain adoption. Note that the results of these two studies can be partly due to the sample period under examination, which is in early years of blockchain adoption that might be prone to errors because of the lack of experience with blockchain.

type of information that is prone to accrual management. For example, in accounting transactions that involve estimates and assumptions, such as asset depreciation, amortization, or impairment, there is usually no counterparty and thus no verification of such transactions by a counterparty. In other words, even though blockchain might help reduce the extent of earning management (e.g., backdating or creating fake transactions), it cannot eliminate managers' accounting manipulation given the discretion in accounting choices. Furthermore, as Cong and He (2019) point out, network users can potentially collude under permissioned private blockchain and thus the data is subject to manipulation. After all, agency and incentive issues remain at the core of blockchain economics (Chen et al. 2021). Therefore, whether the adoption of blockchain enhances firms' information quality and thereby leads to increased investment efficiency is an open question.[11]

Biddle and Hilary (2006) find that higher quality accounting information increases firms' investment efficiency by decreasing information asymmetries between firms and investors. Lambert et al. (2007) show that information quality affects firms' real decisions and in turn their cost of capital. Consistently, Zhu (2019) finds that stock price informativeness increases after the introduction of alternative data (such as point-of-sale transactions and satellite images that are not from companies' financial reports) that results in a decrease in information acquisition costs. She further documents that firms covered by the alternative data exhibit higher investment efficiency after such data become available, suggesting that increased price informativeness resulting from the availability of alternative data improves managers' investment efficiency.

As discussed earlier, a few recent studies have shown positive initial stock price reactions to firms' blockchain-related disclosures and announcements, regardless of whether such disclosures and announcements are genuine or speculative (Cheng et al. 2019, Cahill et al. 2020, Autore et al. 2021b). This evidence suggests that firms' blockchain disclosures contain incremental value relevant information that investors react to and trade on.[12] Through their trades, investors likely incorporate their private information about a firm's prospects into stock prices, which could affect price informativeness and in turn managerial learning from prices when making investment decisions (Dow and Gorton 1997, Chen et al. 2007, Foucault and Frésard 2012, Edmans et al. 2017).

Collectively, blockchain adoption likely (though not certain) enhances a firm's overall information transparency as well as information quality. Stock price informativeness increases with information quality. When price informativeness is higher, managers are likely to glean more decision-relevant information from prices, resulting in higher investment efficiency (as reflected in higher investment-price sensitivity). This leads to the following hypothesis (stated in the alternative form).

Hypothesis. *Firms exhibit higher investment efficiency after they adopt blockchain technology in their business, all else being equal.*

3. Research Design

Similar to a recent blockchain study by Cheng et al. (2019), we use blockchain keywords (e.g., "blockchain" and "block chain") in a full-text search of 8-K filings on the SEC Electronic Data Gathering, Analysis, and Retrieval (EDGAR) system to gather our blockchain data.[13] These search terms provide an initial sample of 1,409 blockchain-related announcements/disclosures during January 1, 2013 to December 31, 2019.[14] As most firms announce their blockchain adoption in press releases, which often triggers a 8-K filing, we rely on 8-K filings to identify whether a firm adopts blockchain.[15]

To identify a firm's commitment to blockchain adoption, three independent coders, one author, and two research assistants conduct an independent review of each disclosure.[16] We first remove 608 duplicate or irrelevant announcements if 8-K reports contain (1) generic news without indicating firm-specific blockchain adoption; (2) overall interests or future plans towards purchasing cryptocurrencies or blockchain-related businesses; (3) a firm's name or

[11] We perform a preliminary analysis on the effect of blockchain adoption on accounting restatements and document weak evidence that blockchain adoption in year t is negatively associated with accounting restatements in year t+1 (significant at the 10% level in a one-tailed test).

[12] Consistently, Yen and Wang (2021) find that blockchain-related disclosures in firms' annual reports are value relevant.

[13] We also conduct a bag-of-words approach to validate our sample by re-checking blockchain keywords in 8-K filings.

[14] We select the period of 2013-2019 because the first blockchain announcement occurred in January 2013 (as in Cheng et al. 2019). However, the first actual adoption of blockchain in our sample, which we manually verified through 8-Ks, was in May 2014. We end our sample period in 2019 because this is the last year for which we had full-year data when we started this study.

[15] A research note by Foster and Xin (2022) indicates that companies in most industries do not disclose or discuss their use, exploration, or development of blockchain in 10-K filings. Instead, many companies mention it in their press releases.

[16] The interrater reliability among these coders is 93%, which is well above the recommended threshold of 70% (Cohen 1960). Follow-up discussions for any disagreements between coders are reconciled, which ensures greater fidelity of the coding scheme.

URL with the term "blockchain" only; (4) the benefits of integrating with other technologies;[17] and (5) other collaborative events with non-publicly traded firms, including universities, government-related agencies, and foreign private firms. We also eliminate 167 announcements unrelated to current blockchain applications, mining, infrastructure, or products/services, as the commitment to blockchain adoption is unclear for these cases. We further delete 153 subsequent blockchain announcements and keep only the initial announcements. Finally, we drop 416 observations because of a lack of coverage by Compustat. After this filtering process, we retain 65 announcements between May 2014 and December 2019, corresponding to 349 firm-year observations related to blockchain adoption. To further ensure the time of actual blockchain adoption, we manually check media mentions of firms' blockchain implementation from LexisNexis Academic news database by validating blockchain "went-live" announcements along with the names of popular blockchain vendors.[18] In our sample, we define blockchain adopters as firms that implement blockchain technology at any point in time during the sample period.

To construct other regression variables used in our analyses, we obtain financial data from Compustat, analyst data from Thomson Reuters' I/B/E/S, internal control data from Audit Analytics, and institutional ownership data from Thomson Reuters' 13F Holdings.

3.1. Research Model

We develop our empirical framework based on Chen et al. (2007), among others, to measure investment efficiency by investment sensitivity to stock price (*Invest*). To test our hypothesis, we estimate the impact of blockchain adoption on investment efficiency using the following regression model:

$$Invest_{it+1} = b_0 + b_1\, Q_{it} + b_2\, Blockchain_{it} \times Q_{it} + b_3\, Blockchain_{it} + Firm\ Fixed\ Effects + Year\ Fixed\ Effects + e_{it+1} \quad (1)$$

where subscripts i and t indicate firm and year, respectively. The dependent variable $Invest_{it+1}$ is total investment at year t+1, measured as the sum of capital expenditure and R&D expense scaled by lagged total assets. The variable Q_{it} is an adjusted measure of stock price, calculated as the sum of the market value of equity and total assets less the book value of equity scaled by total assets. The variable $Blockchain_{it}$ is an indicator variable equal to one in the year and after a firm adopts blockchain technology, and zero otherwise. We include firm and year fixed effects to control for unobserved heterogeneity across firms and years and adjust standard errors for heteroskedasticity and firm-level clustering.

The difference-in-differences model in Equation (1) compares investment-price sensitivity before versus after blockchain adoption between treated (i.e., adopters) and control firms (i.e., non-adopters). Note that due to the way the variable $Blockchain_{it}$ is defined, this variable is equivalent to an interaction term between an indicator for the treatment group (i.e., adopters) and an indicator for the post-treatment period (i.e., after adoption) in a standard difference-in-differences model (i.e., *Treated* × *Post*). The coefficient on the interaction term $Blockchain_{it} \times Q_{it}$ (i.e., b_2) therefore captures the change in investment-price sensitivity for adopters after the adoption of blockchain compared to non-adopters.[19] We predict b_2 to be positive if blockchain adoption is associated with an improvement in firms' investment efficiency.

A major concern with our empirical approach is the endogeneity of blockchain adoption. Indeed, a firm's decision to adopt blockchain technology in business processes may reflect underlying firm characteristics, which could also affect its investment propensity. Failure to adequately control for these characteristics would create an omitted variable bias, resulting in incorrect inferences of the relation between *Invest* and *Blockchain* × *Q* (Shipman et al. 2017).[20] We employ two different techniques in order to achieve covariate balance. First, we use entropy balancing to obtain a sample of non-adopters that exhibits covariate balance with the sample of blockchain adopters (Heinmueller 2012). Entropy balancing assigns weights to non-adopters so that differences in the mean, variance, and skewedness of the distribution of the selected variables are minimized

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[17] For example, artificial intelligence (AI), which can simulate human judgment by classifying, recording, analyzing, and making decisions related to real-time data, and the internet of things (IoT), which can create devices that can take physical actions based upon information contained in blockchain.

[18] The list of popular blockchain vendors is constructed from HFS Research (2018) (http://blockchain.cs.ucl.ac.uk/wp-content/uploads/2019/02/RS_1901-HFS-Top10-Blockchain-Services.pdf), Juniper Research (2019) (https://www.ibm.com/downloads/cas/POPANVJW), and Bitcoin.com (2020) (https://news.bitcoin.com/7-of-the-worlds-largest-blockchain-as-a-service-enterprises/).

[19] The variables identifying the treatment group (i.e., blockchain adopters) and the post-treatment period (i.e., after adoption) are subsumed by firm and year fixed effects, respectively.

[20] If the omitted firm characteristics are time-invariant, the inclusion of firm fixed effects in Equation (1) would help mitigate the endogeneity concern related to a firm's choice to adopt blockchain.

across blockchain adopters and non-adopters.[21] Second, we match each blockchain adopter with the closest (the nearest neighbor) non-adopter using propensity score matching with common support and without replacement (Tucker 2010, Roberts and Whited 2013). The propensity score matched sample contains 404 observations, with 202 blockchain adopters and 202 non-blockchain adopters.[22] Further, we perform additional analysis on dynamic effects of blockchain adoption to mitigate the concern of reverse causality and estimate the regression alternatively using the Heckman two-stage method to address the issue of self-selection bias. We also conduct falsification tests using speculative blockchain adoption and a pseudo adoption year to lend credence to our main results.

4. Empirical Analyses

4.1. Descriptive Statistics

Panel A of Table 1 shows descriptive statistics on variables used in Equation (1). On average, blockchain adopters have higher investment levels in t+1 ($Invest_{it+1}$) than non-adopters (0.252 versus 0.170). The difference in means is positive and statistically significant at the 1% level (t-stat. = 3.025). Blockchain adopters also have a higher Q_{it} relative to non-adopters (41.031 versus 9.466), with the difference in means being positive and significant at the 1% level (t-stat. = 10.048). Panel B shows that the correlation between $Invest_{it+1}$ and Q_{it} is positive and significant, consistent with prior studies (e.g., Baker et al. 2003, Chen et al. 2007), whereas the correlation between $Blockchain_{it}$ and Q_{it} is positive but statistically insignificant. $Blockchain_{it}$ is positively correlated with $Invest_{it+1}$ using the Pearson estimation, but the correlation coefficient becomes insignificantly different from zero when the Spearman estimation is employed.[23]

Panel A. Descriptive Statistics

	N	Mean	SD	P25	P50	P75	t-test (t-statistics)
Blockchain adopter							
$Invest_{it+1}$	202	0.252	0.668	0.002	0.048	0.183	
Q_{it}	202	41.031	103.342	1.391	2.808	11.621	
Non-blockchain adopter							
$Invest_{it+1}$	31,288	0.170	0.382	0.023	0.064	0.157	3.025***
Q_{it}	31,288	9.466	43.871	1.144	1.702	3.152	10.048***
Total							
$Invest_{it+1}$	31,490	0.171	0.385	0.023	0.064	0.158	
Q_{it}	31,490	9.669	44.574	1.145	1.706	3.168	

4.2. Main Results

Table 2 presents the results from estimating Equation (1). Column (1) shows the results from an unmatched sample of blockchain adopters and non-adopters using an ordinary least squares (OLS) regression. Consistent with prior research, we find that firms experiencing an increase in stock price in year t (Q_{it}) have greater investments in year t+1 ($Invest_{it+1}$). The coefficient on Q_{it} is positive and statistically significant at the 1% level (coef. = 0.003; t-stat. = 9.371).

Consistent with our hypothesis, we find that investment-price sensitivity becomes higher for firms adopting blockchain in their business processes in the post-adoption period than for firms that do not adopt blockchain, as evidenced by the interaction term $Blockchain_{it} \times Q_{it}$. The coefficient on $Blockchain_{it} \times Q_{it}$ is positive and significant at the 5% level (coef. = 0.029; t-stat. = 2.515). In terms of economic significance, this result suggests that the investment sensitivity to stock price is 2.9 percentage points higher for firms adopting blockchain technology in the post-adoption period relative to non-adopters.

Column (2) shows the regression results from Equation (1) using an entropy balanced sample of blockchain adopters and non-adopters. We find results similar to those shown in Column (1). The coefficient on Q_{it} is positive and significant at the 5% level (coef. = 0.003; t-stat. = 2.437). Moreover, consistent with our prediction of higher investment efficiency for firms implementing blockchain technology, we find a positive and statistically significant coefficient on $Blockchain_{it} \times Q_{it}$ (coef. = 0.029; t-stat. = 2.231).

Column (3) shows the regression results after matching each blockchain adopter with the closest (the nearest neighbor) non-adopter using propensity score matching with common support and without replacement.[24] In line with the analysis above, the coefficient on Q_{it} is positive and statistically significant at the 5% level (coef. = 0.004; t-stat. = 2.057), and the coefficient on $Blockchain_{it} \times Q_{it}$ is positive and significant at the 1% level (coef. = 0.030; t-stat. = 2.800).

Overall, the results in Table 2 are consistent with our hypothesis that firms exhibit higher investment

[21] Because of its weighting mechanism, entropy balancing allows us to retain all 31,490 firm-year observations in the entropy balanced sample.

[22] For both entropy balanced and propensity score matched samples, we predict the likelihood of blockchain adoption using the following model: $Pr(\textit{Blockchain Adopter}_{it} = 1) = b_0 + b_1 Q_{it-1} + b_2 Size_{it-1} + b_3 \textit{High Tech}_{it} + \textit{Industry Fixed Effects} + \textit{Year Fixed Effects}$.

[23] The estimate of variance inflation factors (VIFs) is 1.06, suggesting that multicollinearity is less of a concern.

[24] Untabulated results show that the covariate balance assumption for the propensity score matched sample is satisfied. The differences in means between blockchain adopters (i.e., treatment group) and non-adopters (i.e., control group) for Q_{it-1} (coef. = 1.969; t-stat. = 0.193), $Size_{it-1}$ (coef. = 0.142; t-stat. = 0.337), and $\textit{High Tech}_{it}$ (coef. = 0.055; t-stat. = 1.097) are statistically indistinguishable from zero.

efficiency (proxied by investment-price sensitivity) after they adopt blockchain in business processes.

Effects of Blockchain Adoption on Investment Efficiency

This table shows regression results on effects of blockchain adoption on investment efficiency using a sample of U.S. listed, non-financial and non-utility firms over the years 2014-2019. Appendix 2 provides variable definitions. The t-statistics, adjusted for heteroskedasticity and firm-level clustering, are reported in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.

	(1) $Invest_{it+1}$	(2) $Invest_{it+1}$	(3) $Invest_{it+1}$
	Unmatched sample	Entropy balanced sample	PSM sample
Q_{it}	0.003***	0.003**	0.004**
	(9.371)	(2.437)	(2.057)
$Blockchain_{it} \times Q_{it}$	**0.029****	**0.029****	**0.030*****
	(2.515)	**(2.231)**	**(2.800)**
$Blockchain_{it}$	-0.061	-0.068	-0.063
	(-0.616)	(-0.748)	(-0.917)
Intercept	0.166***	0.128	0.124
	(36.250)	(1.529)	(0.965)
Firm FE	Included	Included	Included
Year FE	Included	Included	Included
Adj. R-squared	0.074	0.494	0.238
Observations	31,490	31,490	404

4.3. Additional Analyses

The stage of investment in blockchain technology differs across firms that adopt blockchain. Some may have a more advance stage of investment (i.e., beyond the R&D phase) than others. Therefore, depending on the stage of blockchain investments, the impact of blockchain adoption on investment efficiency is likely to vary among blockchain adopters. We expect that only firms that are in a more advanced stage of investment in blockchain technology would exhibit higher investment efficiency after adoption.

We categorize each firm's blockchain investments into three stages. Stage 1 includes firms with blockchain-related R&D projects. We characterize Stage 1 as an early stage of investment because firms at the R&D stage are unlikely to fully utilize blockchain technology. Stage 2 consists of firms that have made blockchain-related investments, including subsidiary investments. We characterize Stage 2 as a medium stage of investment in blockchain technology because it is unclear whether firms can completely benefit from blockchain at this stage. Stage 3 comprises firms that have formed strategic alliances, partnerships, and joint ventures with established blockchain firms in implementing blockchain in their business operations. We characterize Stage 3 as an advanced stage of investment because the benefits from blockchain adoption are likely larger when a firm joins a network of established blockchain firms.

Additional Analysis Based on the Level of Engagement in Blockchain Technology

This table shows regression results of additional analysis based on the level of engagement in blockchain technology using a sample of U.S. listed, non-financial and non-utility firms over the years 2014-2019. *Blockchain Level* is one if a firm's 8-K filings and attached exhibits indicate one of the following levels of engagement in blockchain technology, and zero otherwise. Level 1: Blockchain-related R&D project. Level 2: Blockchain-related investment, including subsidiary investment. Level 3: Blockchain-related strategic alliance/partnership/joint venture. Appendix 2 provides variable definitions. The t-statistics, adjusted for heteroskedasticity and firm-level clustering, are reported in parentheses. ***, **, and * indicate statistical significance at 1%, 5%, and 10%, respectively.

	(1) $Invest_{it+1}$	(2) $Invest_{it+1}$	(3) $Invest_{it+1}$
	Level 1	Level 2	Level 3
Q_{it}	0.002***	0.002***	0.002***
	(9.267)	(9.238)	(9.276)
$Blockchain\ Level_{it} \times Q_{it}$	**0.001**	**0.009***	**0.031****
	(0.655)	**(1.674)**	**(2.343)**
$Blockchain\ Level_{it}$	0.126	0.099	-0.110
	(1.179)	(0.938)	(-1.120)
Intercept	0.166***	0.166***	0.166***
	(36.494)	(36.524)	(36.397)
Firm FE	Included	Included	Included
Year FE	Included	Included	Included
Adj. R-squared	0.069	0.072	0.073
Observations	31,490	31,490	31,490

Table 3 as above presents regression results of the analysis based on the stage of investment in blockchain technology. Consistent with our expectation, we find that the effect of blockchain adoption on investment efficiency is statistically insignificant for firms in an early stage (i.e., Stage 1) but is positive and significant for firms in more advanced stages (i.e., Stage 2 and Stage 3). Specifically, the coefficient on $Blockchain\ Level_{it} \times Q_{it}$ is 0.009 (t-stat. = 1.674) for Stage 2 in Column (2), and the coefficient is 0.031 (t-stat. = 2.343) for Stage 3 in Column (3), suggesting that the magnitude of the effect of blockchain adoption on investment efficiency increases with the stage of investment in blockchain technology.[25]

5. Conclusions

This paper investigates the relation between blockchain adoption and investment efficiency. Firms in various industries have started applying blockchain in their business and operations, seeking to improve efficiency and to develop new business models and revenue sources. Our study documents that relative to non-adopters, adopters exhibit higher investment efficiency after they adopt blockchain technology in their business. Our cross-sectional analysis indicates that the positive effects of blockchain adoption on investment efficiency are concentrated in firms with

[25] We repeat the analysis using entropy balanced and propensity score matched samples and find similar results.

poor information environments. Additional analyses show that only firms that are in a more advanced stage of investment in blockchain technology experience increased investment efficiency after blockchain adoption. Moreover, the effects of blockchain adoption on investment efficiency continue another year after adoption. Our results are robust to a battery of tests that address endogeneity concerns.

Our study relates and adds to the streams of research on blockchain, investment efficiency, and managerial learning from stock price. Our findings provide some of the first empirical evidence on the real effects of blockchain adoption. As companies are interested in blockchain applications that can create value and improve efficiency, whether and how blockchain adoption affects firms' investment efficiency is hence relevant for businesses to know. By documenting the impact of blockchain adoption on investment efficiency, our study provides implications for interested parties, such as business communities, in assessing the real effects of adopting blockchain technology in business. As discussed in the introduction, due to the caveats our study is subject to, we caution the reader against drawing causal inferences on the relation between blockchain adoption and investment efficiency and that our results might be overstated due to the potential blockchain adoption survival bias.

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