Blockchain Technology and Environmental Efficiency: Evidence from US-Listed Firms

Abstract

In this paper, we examine the relationship between the adoption of blockchain technology and environmental efficiency using a sample of U.S. firms over the 2015-2019 period. Our results show that the adoption of blockchain technology is positively and significantly associated with environmental efficiency, suggesting that the use of Blockchain improves environmental sustainability. In further analyses, we find that the relationship between Blockchain and environmental efficiency is more pronounced for firms in the financial and technological industries. Our findings are also robust to other methods that control for endogeneity, including the difference in difference regressions and Propensity Score Matching. Overall, we provide empirical evidence that can incentivize business leaders and policymakers to adopt innovative technologies such as Blockchain.

Keywords: Blockchain technology; Carbon emissions; environmental efficiency, environmental sustainability

1.0.Introduction

Blockchain, a disruptive innovation that emerged as a cryptocurrency, has rapidly grown as the digital technology that provides internet of value for both firms and their customers (Tapscott & Tapscott, 2016). As a distributed ledger technology, it is an alternative to the usual ledger-book, which records and shares data across multiple data stores (World Bank, 2019). Unlike the other digital ledger-books, Blockchain offers irreversibility of records and transparency with pseudo-anonymity for all its users (Iansiti & Lakhani, 2017). Behind blockchain technology are cryptocurrencies, which enable easy transfer of funds between two parties at a reduced cost with less paper trail (Boshkov, 2018). Given the uniqueness of the Blockchain and its vast benefits, many firms have embraced the platform with successful projects. The annual spending on blockchain technologies has grown three times since 2017. It has been projected that by 2023, nearly $16 billion would be spent by firms, especially in insurance, gaming, and cannabis (CBInsights, 2020).

As a disruptive innovation, blockchain technology has the potential to affect every facet of a firm's operation, including its environmental sustainability (Kouhizadeh & Sarkis, 2018; Morkunas et al., 2019). However, existing literature has primarily focused on only the financial implications and, to some extent, privacy and transparency of transactions (Cole et al., 2019; Hasan et al., 2020; Pan et al., 2020; Ying et al., 2018). Secondly, the US growing digital market economy have question the importance of cryptocurrency, which IBM alone invested $200 million to research on blockchain technology (Daley, 2021). This is proving blockchain as option for improving the future. Little is known about how the adoption of this technology affects the environmental efficiency of firms. Therefore, in this study, we examine the impact of the Blockchain on environmental efficiency at the firm level.

Contrary to other areas of firm operations, where the effect of Blockchain is quite obvious, the environmental consequence of Blockchain is not straightforward. There are two competing views on blockchain technology that might affect the environmental sustainability of firms. On the one hand, critics of blockchain technology argue that Blockchain is not environmentally sustainable because of the large amount of energy required to power servers and computer hardware for keying algorithms, processing, and computation of information (Kouhizadeh & Sarkis, 2018; Manganello, 2019; Truby, 2018). Also, the process of mining cryptocurrency involves the use of cryptocurrency software that sends data to servers, which also require physical rooms in buildings and consume vast amounts of energy (Potter, 2020). Thus, the mining of cryptocurrency is deemed to rely heavily on dirty energy sources, which are harmful to the environment.

On the other hand, proponents of blockchain technology argue that its efficient and proper use can help mitigate the carbon emissions, especially at the firm level (Adams et al., 2018; Hasan et al., 2020; Kouhizadeh & Sarkis, 2018; Pan et al., 2020; Saberi et al., 2018). These studies argue that Blockchain helps firms to cut down waste in the paper trail, the cost of intermediaries and its related documentation and transports, office spaces, and numerous computer system, and to some extent, the consumption of energy. Saberi et al. (2018) posit that blockchain technology induces new ways of green production. They further argue that Blockchain can be used for monitoring and storing environmental-related data in real-time for timely decisions on carbon emissions. For instance, Nari is one such firm that has used blockchain tools to mitigate the excess of carbon emission on the surface (Manganello, 2019). In fact, energy transactions, in general, can occur in real-time, using smart sensors connected to blockchain ledgers (BitIRA, 2019).

Aside from reducing transaction costs, Blockchain makes it more affordable to protect and track records without involving much office space and processes. Hence, it enables firms to operate environmentally efficiently by using fewer resource inputs, which generate less carbon emissions. Potter (2020) argues that the energy-hungry criticism of Blockchain's long past because it is bitcoin, not Blockchain that is labor-intensive, and more importantly, the latest blockchain applications use less energy. Thus, the positive effect of Blockchain is consistent with the ecological modernization theory, which states that technology is essential for achieving rapid growth and a sustainable environment at the same time (Bergendahl et al., 2018).

These contrasting arguments on the blockchain-environmental sustainability nexus provide compelling motivation to examine whether the use of blockchain technology is an enabler or constrainer of environmental efficiency. To do this, we use data on 103 large US-listed firms over five years. We use a small sample size and short period because blockchain technology is a relatively new concept that has not been adopted by many firms. Our sample frame is consistent with other studies that provide an empirical analysis of the effect of Blockchain (Hasan et al., 2020; Pan et al., 2020). Environmental efficiency is defined as the amount of carbon emission generated by a firm to achieve its net income. Mathematically is calculated as the ratio of net income to total carbon emission. Information on blockchain adoption is collected from annual reports and Forbes Blockchain 50 annual presentation (Forbes, 2018, 2019, 2020). We employ a fixed-effect model to control for the average differences across the firms.

Our results show that the use of Blockchain is positively and significantly associated with an increase in environmental efficiency. The results, therefore, suggest that firms using Blockchain are efficient in generating less carbon emission to achieve high profit. However, in further analyses, we find that the benefit of Blockchain in improving environmental efficiency is more pronounced for firms in the financial and technological industries compared to others. We attribute this sectorial difference to the earlier and wide use of Blockchain in the financial and technological industry. Our results are robust to the alternative measurement of environmental efficiency and additional control, such as growth opportunities. Although there is less likelihood of reverse causality between Blockchain and environmental that can cause endogeneity problems, we still use robust identification strategies, including and the difference in difference regressions and Propensity Score Matching, to ensure our results are not sensitive to endogeneity problems.

Our findings that the use of Blockchain improves environmental efficiency provides empirical evidence for supporters of blockchain technology and also extend the operationalization of ecological modernization theory. More importantly, they provide timely evidence to business leaders and policymakers on the environmental sustainability benefit of Blockchain in this era, where the technology is growing rapidly but not without controversies. The blockchain market promises to raise its Compound Annual Growth Rate (CAGR) to 67.3%, amounting to $39.7 billion by 2025 (Markets and Markets, 2020), but privacy and security issues around it are driving negative publicity.

Our study is distinctively different from existing literature on blockchain technology because we focus on environmental sustainability, a global issue which needs attention (Hasan et al., 2020; Lohmer et al., 2020; Pan et al., 2020; Saberi et al., 2018; Wamba et al., 2020; Ying et al., 2018). To the best of our knowledge, it is the first of its kind on the relationship between blockchain adoption and environmental efficiency. The findings of our study, which support the fundamental argument of the ecological modernization theory that rapid and high performance can be decoupled from the environment deterioration through technology, provide empirical evidence of the applicability and operationalization of the theory with regards to Blockchain (Bergendahl et al., 2018). We, therefore, make an incremental contribution by extending the literature on the consequence of Blockchain to the environment, an area where the effect is not so obvious.

Beyond literature contribution, this study serves as a tool for promoting the gig economy and transparency in the government system. Through blockchain, the government can easily keep track of natural resources extraction, land management, and deforestation levels transparently. As data on the blockchain cannot be altered, the whole tracking process can be put under scrutiny to prevent any third party from manipulating the system. This will not only revolutionize access to capital but also open up a whole new class of potential investors. Similarly, the transparency transaction on blockchain makes it incorruptible. Therefore, we recommend that government and policymakers commit to shifting government contracts and financial spending on blockchain by employing the partnerships of private individuals in the blockchain markets.

The remainder of the paper is structured as follows. Section 2 provides a brief background on Blockchain. The literature review is presented in Section 3. We present the research design in Section 4. Results and discussions are presented in Section 5, whilst the conclusion and policy implications are presented in Section 6.

2.0.Background and literature review

[redacted]Brief background of Blockchain and its use

Satoshi Nakamoto coined the present-day blockchain technology in 2008 by improving on the design through the aid of Hashcash, which enables the user to time-stamp block with securing trusted party permissions (Morkunas et al., 2019). Following the *Nakamoto scorecard*, blockchain technology made its public debut in 2009. Since then, the Ethereum blockchain system was born, and further development was financed by an *online crowd sale* (Morkunas et al., 2019).

Blockchain technology is a special distributed database with a decentralized management system, with a record of transactions on peer–to–peer network among participants (Crosby et al., 2016). The records in each ledger are protected by cryptography with hash functions to link ledgers as chains, unique private key per transaction, and participant and consensus mechanisms (Swan, 2015). The essential features influencing the use of Blockchain are its irreversibility and immutability to manipulation. Besides, Blockchain offers a high level of transparency without comprising on privacy and security. One point of attraction of Blockchain to firms, aside from being a potential currency, is the disintermediation and automation of transactions through smart contracts (Babich & Hilary, 2019; Pournader et al., 2020). In this global village and interconnected world, cost and risk of intermediaries cannot be underestimated (Potter, 2020); hence a simple, cost-efficient, and secure technology like Blockchain is timely.

There are different configurations of Blockchain, and these differ based on access control (public vs. private) and the consensus mechanism (permission vs. permissionless) (Lohmer et al., 2020). Cryptocurrencies such as Bitcoin and Ethereum, which are the earlier application of Blockchain, are configured as public and permissionless. But the use of blockchain technology in firms are configured as private and permissioned networks (Wang et al., 2019). Although every firm uses blockchain technology in different areas of operations, its applicability focuses on reliability, traceability, and storage of records. It is also used to execute smart contracts. For example, Barclays Bank uses its blockchain technology to execute a trade transaction between Ornua and Seychelles Trading Company (Barclays Bank, 2016)

Blockchain continues to grow globally because it provides the most secure and safe online transaction that has shaken the face of industries, particularly in this pandemic era. Due to its uniqueness and benefit, firms and professionals have adopted the blockchain technology. In the area of banking, Barclays and Swiss bank UBS are reportedly using Blockchain in ways to minimize the cost of middlemen, which is about $ 20 billion. Further, Blockchain companies such as Ripple and BanQu have partnered with financial institutions such as Santander, Western Union, and ABInBev to ensure smooth payment to cassava farmers in Zambia (CBInsights, 2020).

[redacted] Literature review

Despite the prominence of Blockchain as a currency platform or application in firms' operations, there is a paucity of studies on the consequence of blockchain technology. Existing studies are dominated by conceptual analysis, commentaries, expositions, survey-based and case studies (Adams et al., 2018; Kouhizadeh & Sarkis, 2018; Lohmer et al., 2020; Morkunas et al., 2019; Saberi et al., 2018; Truby, 2018; Ying et al., 2018). Therefore, we expand the review to cover areas other than the environment.

According to the ecological modernization theory, technology is an indispensable solution to environmental degradation resulting from global rapid economic growth (Bergendahl et al., 2018). However, technology may not always be a solution. In some cases, it could even be the enable of environmental degradation (Adams et al., 2018; Potter, 2020). Critics of Blockchain argue that the technology behind Blockchain as a currency or digital ledger is power thirty. Thus, blockchain operations require large amounts of energy resources, which threaten environmental sustainability (Kouhizadeh & Sarkis, 2018; Truby, 2018). However, these arguments are more focused on bitcoin mining, which is a different albeit an integral blockchain technology. Truby (2018) argues that the use of blockchain technology is an inefficient use of limited energy resources for the financial gain of few people at the expense of the environment. Similarly, de Vries (2018) estimates the electricity consumption of the bitcoin miner machine to be 8.93 gigawatts, which puts the consumption of bitcoin at about 0.15% of global electricity energy (Washington Post, 2018).

More so, Blockchain is still at an early stage of development, and such is likely to distort the already instituted business model within the logistic and supply chain management (Queiroz & Wamba, 2019). Blockchain technology may not be an option to transform the energy sector because of the broader constraint it posed, such as grid reliability and security issues, energy consumption issues, regulatory risk, and the technology uncertainty for the users (Bürer et al., 2019).

Despite these criticisms, there is growing evidence of how Blockchain is improving the operational efficiency of firms, which translates to environmental sustainability. Adams et al. (2018) opine that blockchain technology can ensure the achievement of the Sustainable Development Goals with particular reference to the environment. Truby (2018) reports that some industries, such as financial and supply chain, are already realizing the benefit of blockchain technology on the environment. Lohmer et al. (2020) argue that Blockchain is a promising technology that enhances the supply chain process. Particularly, knowledge sharing and pressure from traders influence the adoption of Blockchain by firms, which has turned-around the supply chain performance (Wamba et al., 2020). Such improvement in the supply chain system could cut the 90% damage to the environment, which is caused by supply chain issues (McKinsey & Company, 2016).

Pinkse (2007) argues that process innovation, such as digital transformation, is a significant determinant of firms' participation in the emission market towards a greener environment. In addition to improving the operational efficiency of a firm, blockchain technology is used for monitoring and storing environmental-related data in real-time for timely decisions (Saberi et al., 2018). Fu et al. (2018) report that the application of blockchain technology in the internal emissions trading system improves transparency and information sharing, providing financial benefits for reducing energy consumption through the trading of emission credits. Prior studies provide evidence on emission reduction as both a strategic concern and a driver of firm performance, including environmental efficiency (Falk & Hagsten, 2020; Lewandowski, 2017; Zhang et al., 2020).

Blockchain technologies have also proven to reduce the risk of doing business and possibly cut-down the transaction cost through the elimination of intermediaries (De Giovanni, 2020). Similarly, using Hainan Airlines as a case study, Ying et al. (2018) find that blockchain technology has added value to the airline company by eliminating institutional intermediaries. In a sample of 50 listed Chinese firms, Pan et al. (2020) report that the use of blockchain technology increases asset turnover and reduces sales expenses. Consistently, using a sample of 48 listed Chinese firms, Hasan et al. (2020) also claim that firms using blockchain experience high performance. They support their findings with the transactional cost dynamics of blockchain technology.

Saberi et al. (2018) report that some firms who have developed blockchain technology have already realized savings from the environmental –industrial supply chain efficiencies; hence the concomitant economic savings using Blockchain can induce firms to consider its environmental efficiency as well. However, the authors further argue that Blockchain could be another utopia as many technologies which has come to pass. Other studies like Chapron (2017) believe that Blockchain can effectively protect the environment but are skeptical about the current weak governance, which is likely to make it counter-productive to environmental sustainability. Turby (2020) suggests that the possibilities of Blockchain improving environmental sustainability are endless but can only possibly materialize if there are incentives to develop environmentally friendly blockchain platforms.

Looking at the previous studies, which have mainly focused on the adoption and finance trading, this present study which focuses on the extent to which the use of blockchain technology is associated with the environmental efficiency of a firm, making it the first to consider the nexus between blockchain and carbon dioxide emission. By doing this, valuable reference will be added to the existing literature, and policymakers will further understand specific policies that can be targeted during the blockchain innovation era to mitigate the spread of carbon dioxide emissions.

3.0.Research design

3.1.Data and sample

Our sample selection begins with all large Listed firms in the USA between 2015-2019[1]. We focus on this set of firms for three reasons. Firstly, blockchain technology requires large investments, which only large companies can afford. According to the yearly Forbes Blockchain 50 report (Forbes, 2018, 2019, 2020), only firms with sales in billions of USD are investing in blockchain technology. Secondly, data on carbon emission is only available for these large firms. Thirdly, these firms have a significantly high level of carbon emission and, therefore, have higher incentives to mitigate their environmental footprint (The Guardian, 2017). We drop all firms with missing data on carbon emissions and other variables of interests such as sales and net income. Next, to ensure adequate and fair matching of adopting and non-adopting firms, we exclude firms at most $10 billion in average sales over the five years since we do not find any firms in that category to have adopted blockchain technology.

[1] Historically, the blockchain gained recognition on the US stock market in 2015 (Gupta, 2017).

Our final sample consists of 507 firm-year observations covering 103 firms. We collect all firm-level data from Datastream.

3.2.Measurement of variables

Dependent variable – Our main dependent variable is Environmental efficiency, which we measure by the amount of CO_2 emissions generated to attain the net income for the year. Therefore, we compute it as net income divided by total CO_2 equivalent emissions. Higher values imply that the firm is generating high returns with less waste or emissions. For robustness checks, we also measure environmental efficiency by scaling total CO_2 emissions by firm sales.

Independent variable – Blockchain: We measure blockchain adoption as a binary variable equal to 1 if the firm has adopted blockchain technology and 0 otherwise. There is no specific database on firm blockchain adoption. Therefore, our primary source of information is the annual reports of the firms. We search through the reports to identify any mention of blockchain adoption. We key in "blockchain" or "block" in the search function to identify all information on the use of Blockchain in the firm annual report. In addition, we use other credible sources such as Forbes Blockchain 50 (Forbes, 2018, 2019, 2020). Forbes publishes the top 50 firms using Blockchain for 2018, 2019, and 2020. Where possible, we also use newswire on firms to confirm the information on blockchain adoption (Hasan et al., 2020; Pan et al., 2020).

Control variables: Following prior studies such as Alam et al. (2019), Lee & Min (2015), we control for other firm characteristics that may influence the environmental performance of a firm. We use total assets to control for the differences in firm size (*Firm Size*). We predict a positive relationship between *Firm Size* and environmental efficiency because we expect large firms to have the resources to invest in energy-efficient operations. We also expect *Leverage*, which we compute as the ratio of total debt to total assets, to be positively and significantly associated with environmental efficiency because good environmental practices make firms appear sustainable for capital providers. We further control for financial performance using the ratio of net income to total assets (*Return on Assets)* and size of business operations on environmental productivity using total revenue (Revenue). Finally, we include the value of intangible assets, *Intangible asset,* to control for the impact of technological advancement, such as research and development on environmental efficiency.

[Insert Table 1: Description and sources of variables]

3.3.Estimation technique

Following prior studies (Alam et al. 2019; Lee & Min, 2015), we begin the econometric modeling with a fixed effect ordinary least square regression augment it with year and industry year as the final model. The fixed-effect model mitigates the effect of omitted variable bias and also controls for year fluctuations. Arguably, the environmental efficiency of a firm largely depends on the change of industry output and the business cycle. Therefore, to further ensure the robustness of our results, we include the year and industry effect to capture the effect of time variation on both the adoption of blockchain and carbon emissions.

Our final model is as follows.

$$Environmental\ efficiency_{it} = a + \beta_1(Block\ chain)_{it} + \delta_2(Control\ variables)_{it} + \delta_3 \sum(Year\ effects)_t + \delta_4 \sum(Industry\ effets)_i + \varepsilon_{it} \dots \dots \dots EQ1$$

Where for each firm i and t represent firm and time respectively, and ε_{it} is the associated error. All variables are defined in Table 1.

4.0.Results and discussion

4.1.Univariate results

Table 2 presents the descriptive statistics of the variables used for the estimations. The statistics include the mean, 25th percentile, median, 95th percentile, and standard deviation. *Blockchain* has a mean of 0.208 and a standard deviation of 0.406. This shows a moderate but growing use of blockchain technology among the firms. In the sample of 103, 43 firms representing 41.7 percent of the total sample are using blockchain technology in different formats and areas as of 2019. The mean of environmental efficiency measured by net income (11.18) indicates that, on average, the sample firms generate profit, which is equivalent to 11.18 times their total carbon emissions, but the high standard deviation shows large variations among the firms. This pattern is similar to environmental efficiency measured by revenue. The positive value of return on assets across all the statistics implies that all the sample firms, on average, have been profitable over the five years.

[Insert Table 2 Summary statistics]

We perform correlation analysis to check the appropriateness of variables with regard to potential multicollinearity issues. The correlation matrix is presented in Table 3. We observe two interesting findings from the table. Firstly, there is a large and positive correlation (0.78) between the two measurements of environmental efficiency, indicating that they are appropriate alternative measurements to each other. Secondly, the correlation between the two environmental efficiency measurements and Blockchain is positive, which gives precursory evidence that blockchain technology improves environmental efficiency. However, with the exception of the dependent variable and its alternative measurement, the correlation among other variables are less than 0.5, which is below the threshold of 0.8 to pose any threat of multi-collinearity (Field, 2000; Tabachnick & Fidell, 2013).

[Insert Table 3 Correlation matrix]

4.2. Main results

The OLS estimations are presented in Table 4. We present the results of both income-based environmental efficiency and sales-based environmental efficiency together as a robustness check on the measurement of the dependent variable. Following Alam et al. (2019), we present the results in three specifications, without control variables, with controls, and with year industry effect, respectively. The first three columns (1-3) contain the results of the income-based environmental efficiency. The coefficient of *Blockchain* in all the three columns (6.492***; 5.799***; 4.375***) is positive and highly significant at 1%. The results, therefore, suggest that the adoption of blockchain technology has a significant impact on mitigating the environmental footprints of firms. The results remain statistically similar even after controlling for firm characteristics, year, and industry effects. The results are not only statistically significant but economically meaningful. For instance, the coefficient of *Blockchain* in column 3 of the table is 4.375. This means that all else equal, a one-standard-deviation increase in the use of Blockchain increases environmental efficiency by 1.75, which corresponds to about 15% of the sample mean. In columns 4-6, we use the alternative measurement of environmental efficiency. Similar to the primary variable, we estimate the models based on three specifications without control variables, with control variables, and with year industry effect, respectively. The coefficient of *Blockchain* remains positive and significant at 5 percent or better in all the three columns (4-6), confirming the robustness of our findings.

Overall, the results in Table 4, implies that the use of blockchain technology significantly improves firm operational efficiency, causing a decrease in energy consumption and waste, consequently resulting in a reduction in carbon emissions of the firm. We argue that blockchain technology reduces the use of most stationery items, including papers. Also, Blockchain makes it easy and more affordable to protect and track records without involving many office spaces and processes. Therefore, using blockchain technology enables firms to execute transactions quickly with less resources, which could have generated more carbon emissions. For example, with blockchain technology, a bank will not require additional vehicle or office space to transport or keep records of historical transactions. Blockchain allows firms to keep even confidential records more secure and private without the traditional trail of voluminous papers or electronic storage, which consumes much energy.

[Insert Table 4. Main results]

4.3. Further analysis - Sectoral results

Apart from being a recent innovation, which demands a large initial investment outlay, the blockchain applicability is more dominant in some industries than others, probably due to their nature. According to the Forbes Blockchain 50 (Forbes, 2018, 2019, 2020), the technology is widely adopted by the financial and technology industry compared to other industries. Indeed, the use of blockchain technology started from the banking sector and continues to be a game-changer in that sector. Therefore, our results could be driven by the dominant use of blockchain technology in the financial and technology industry. Although we included industry dummies in our baseline model, which mitigate this potential problem to some extent, it does not eliminate the problem in its entirety. Accordingly, we use a sub-sampling estimation technique to check if the impact of Blockchain differs between financial-technology and other industries.

We split our firms into financial and technology as one group (38 firms) and the remainder of the sample as other industries (65 firms). Next, we run separate OLS regressions for each group using the main dependent variable and its alternative. We present the results for these in Table 5. The results in columns 1-2, which are for financial and technology firms, show that the impact of blockchain technology on environmental efficiency is positive and highly significant at 1 percent. However, the coefficient of Blockchain in columns 3 and 4 is positive but not significant in all cases and even at a lower significance level of 10 percent. Also, the coefficient of *Blockchain* in the financial and technology group is larger than that of the other industry. These results, therefore, imply that the use of Blockchain in improving environmental efficiency and reducing carbon emissions is more beneficial to firms in the financial and technology than firms in the other industry. Having said this, the results could be influenced by the wide use of Blockchain in these two industries. Hence as the applicability of blockchain increases across all the industries, other firms are also likely to realize the benefits.

[Insert Table 5. Sectorial analysis]

4.4. Further analysis – controlling for growth opportunities

In the preceding analyses, we have largely assumed that all our sample firms have an equal level of growth opportunities. However, empirical evidence shows that even large and relatively similar firms can have differential growth opportunities that could impact their operational performance (Hutchinson & Gul, 2004; Rahmandad, 2011; Sardo & Serrasqueiro, 2018) as well the adoption of a specific technology. High growth firms will have an enormous negative impact on the environment due to the high rate of using resources. Alam et al. (2019) find a negative relationship between growth opportunities and carbon emissions of a firm. Nonetheless, firms with high growth opportunities are also more likely to adopt technology to turn opportunities into profit. Given this relationship between growth opportunities and the firm's environmental impact, our results may have been significantly influenced by the growth opportunities of the firms. Therefore, in this section, we include growth opportunities in the equation as a control variable. Following prior studies, we measure growth opportunities of a firm as market value equity plus book value of assets minus book value of equity divided by book value of assets. The results, which are presented in Table 6, show that the coefficient of *Blockchain* remains positive and significant, as reported in the main results in Table 5, and, therefore, confirm the robustness of our findings.

[Insert Table 6: Accounting for growth opportunities]

4.5. Robustness - Endogeneity check

Given that blockchain technology is largely about the privacy and speed of processing transactions, it is less likely that a firm's decision to adopt blockchain technology depends on the environmental efficiency of Blockchain. As such, this should pose little concerns about endogeneity. Nonetheless, a caveat may be that a firm's environmental footprint could influence its decision to adopt efficient operating strategies that reduce waste and energy consumption. Firms are significant contributors to carbon emissions and their impact on increasing global warming. For instance, The Guardian (2017) reports that just 100 firms are responsible for 71 percent of global emissions. To meet social expectations and be responsible citizens, firms are currently looking into different ways of improving their operations, including the adoption of technology to cut down carbon emissions. Therefore, it may be quite plausible for environmental efficiency to dissociate with the implementation of blockchain technology systematically. Such a situation is likely to violate the linearity assumption of our OLS regression leading to spurious results. To address these concerns and other potential endogeneity problems, we follow prior studies such as Alam et al. (2019), Harford et al. (2012) to employ two different identification techniques; Propensity Score Matching and Difference in Difference.

The Propensity Score Matching identification technique-PSM (Lennox et al., 2012; Rosenbaum & Rubin, 1983) allows us to test the change in environmental efficiency as the result of adopting blockchain technology. To do this, we run a logistic regression with Blockchain as a dependent variable and the control variables as explanatory variables based on the Blockchain adopting firms as the treatment group and non-adopting firms as control groups. Next, we use the predicted estimates as propensity scores to form one-to-one matched pairs for blockchain adoption and the resultant difference in environmental efficiency. Our matching reveals nearly indistinguishable features between the treatment and control group except for blockchain adoption. Hence any difference in environmental efficiency can be attributed to the adoption of blockchain technology. The results of the PSM are reported in columns 1 and 2 of Table 7. The results of the matched firm-year observations show that blockchain adoption significantly improves environmental efficiency, confirming the robustness of the findings.

Our dataset, which includes both blockchain adopting and non-adopting firms, enables us to employ the Difference in Difference estimation technique. The essential requirement for using DID is the occurrence of the event and the existence of a control group (Horváth, 2020). The use of blockchain technology is a significant innovation in the operation of a firm. However, as evident in our sample, not all firms are using blockchain technology. In our sample 103 firms, we find that only 47 firms are using blockchain technology as of 2019. We also find 43 of these Blockchain adopting firms began using it from 2017. Therefore, using 2017 as the event date and non-adopting firms as a control group enables us to undertake a difference in difference regression estimation. Because we assign 2017 as the event date, we drop four firms that have been using Blockchain before 2017. Blockchain adopting firms are allocated as the treatment group (*Treatment*), while non-adopting firms are label as a control group. We code 2015 and 2016 as a pre-adopting period and 2017-2019 as a post-adopting period (*Post-adoption)*. Finally, we interact with *Post-adoption* and Treatment to generate our variable of interest (*Post*Treatment*). If our findings that Blockchain has a positive and significant impact on environmental efficiency, then we expect *Post*Treatment* to be positive and significant.

The results of the DID estimations are presented in columns 3 and 4 of Table 4. The coefficient of *Post*Treatment* is positive and significant. This implies that since adopting blockchain technology, firms have a greater environmental efficiency relative to their non-adopting blockchain counterparts. Confirming our main findings that the use of blockchain technology helps firms in reducing their environmental impact. In sum, all the results from both PSM and DID identification strategy provide evidence that our findings are not sensitive to potential endogeneity issues arising from reverse causality or omitted variable bias.

[Insert Table 6. Endogeneity checks]

5.0.Conclusion

Blockchain, the disruptive innovation, which is known as cryptocurrency, is now used in executing and performing different operations in different industries. As with any new technological wave, Blockchain can increase the efficiency of production and consumption of resources (Morkunas et al., 2019). However, it also involves complex operations, which can potentially result in a waste of resources, including natural assets. Although there is a growing number of studies on the consequences of Blockchain on firm performance (Hald & Kinra, 2019; Hasan et al., 2020; Morkunas et al., 2019; Pan et al., 2020; Ying et al., 2018), its effect on the environment remains largely unexplored probably because technology appears to be distant from or have a contradictory effect on the environment. On the one hand, the use of Blockchain may require high energy to power servers and computers, causing an increase in energy consumption and subsequent carbon emissions. On the other hand, Blockchain helps to streamline business operations by cutting waste such as paper trail, cost of intermediaries, and information technology for storage, negotiation, and search cost, hence improving the efficient use of resources, including energy and other natural assets.

Using data on 103 large US-listed firms between 2015 and 2019, we examine the impact of blockchain technology on the environmental efficiency of firms. We measure environmental efficiency as the amount the carbon emission used to generate net income with alternative measurement based on sales. Our results show that blockchain technology has a positive and significant impact on environmental efficiency, suggesting that Blockchain is an environmentally friendly technology that could help to cut down their carbon emission over the years. In further analysis, we find that the relationship between blockchain technology and environmental efficiency is more pronounced in the financial and technology industries than in other industries. Our findings are robust to alternative econometric modeling, including alternative variable specifications, accounting for growth opportunities, year, and industry effect. In further robustness analysis using Propensity score matching (PSM) and Difference in Difference (DID), we confirm that our results of positive and significant effect of blockchain technology on the environment are not sensitive to potential endogeneity problems. In summary, our results lean support to the ecological modernization theory and are consistent with Chen et al. (2020) findings that technological progress reduces carbon emission.

The findings of this study have policy implications for both business leaders and policymakers because it provides empirical evidence on the significance of blockchain technology in addressing climate change, the problem of which firms are the largest contributors.

Given our findings, we suggest that policymakers should aim to encourage firms on the adoption of Blockchain, particularly to the projects that are environmentally sustainable such as renewable energy sources. Further, policymakers should formulate policies that will give incentives to the firms that adopted Blockchain as a way to encourage new firms further to adopt the platform. For instance, the government can provide tax-free for firms that adopt Blockchain with the intent to encourage the use of renewable energy technologies whiles limiting the firms that are not environmentally friendly.

In addition to its policy relevance, our study makes an incremental contribution to different academic frontiers. Firstly, by providing empirical evidence on the impact of Blockchain on the environmental performance of firms, we extend the existing literature on carbon emissions by being the first to examine how the use of innovative technology such as Blockchain helps firms to mitigate its environmental footprint. Secondly, within the scant empirical literature on the consequence of blockchain adoption (Hasan et al. 2020; Pang et al. 2020), our study does not only distinctively provide evidence on from the environmental perspective it also brings findings outside China. Thirdly, in the business strategy environment arena, this study also extends the literature on how a particular business strategy affects the environment. The adoption of blockchain technology is a major business strategy that firms make a strategic decision to enhances their performance over competitors.

Whilst we acknowledge our sample size may be small, it does not represent a major limitation, given that blockchain adoption at the firm level is a relatively new phenomenon and very expensive. We, therefore, consider our current sample size appropriate for providing insights into the benefits of such a new but growing technology. We believe future studies could use large data over the years to examine how blockchain technology affects the environment in different countries and also consider another moderating effect, such as regulation on the use of blockchain technology.

6.0.References

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Table 1. Description and sources of variables

Variable name	Measurement	Source
Environmental efficiency	The proportionate of net income to the total amount of CO2 emission equivalent	Author construction based on data from Datastream
Block chain	Binary variable equal to 1 if a firm has adopted block chain technology or 0 otherwise	Annual report, Forbes Blockchain 50
Firm size	Natural log of total assets	Datastream
Leverage	Total debt scaled by total assets	Datastream
Revenue	Natural log of total sales	Datastream
Intangible assets	The ratio of total intangible assets to total assets	Datastream
Return on assets	The ratio of net income to total assets	Datastream
Growth	Calculated as market value equity plus book value of assets minus book value of equity divided by book value of assets.	Author construction based on data from Datastream

Table 2. Summary statistics

VARIABLES	N	Mean	25^{th}	Median	95^{th}	Std

Environmental efficiency (Income)	507	11.18	0.315	2.789	44.29	25.82
Environmental efficiency (Sales)	507	119.3	9.133	38.98	507.5	225.9
Blockchain	515	0.208	0.000	0.000	1.000	0.406
Firm size	515	18.77	17.70	18.54	21.36	1.386
Leverage	515	0.702	0.560	0.706	0.948	0.197
Revenue	515	17.74	17.18	17.59	19.18	0.721
Intangible	515	0.168	0.0141	0.0876	0.586	0.200
Return on assets	515	0.0459	0.00773	0.0330	0.164	0.0576
Growth	515	0.703	0.562	0.708	0.948	0.197

Table 3: Correlation matrix

	VARIABLES	1	2	3	4	5	6	7	8
1	Environmental efficiency (Income)								
2	Environmental efficiency (Sales)	0.78							
3	Blockchain	0.19	0.14						
4	Firm size	-0.07	-0.09	-0.07					
5	Leverage	0.25	0.34	0.14	-0.11				
6	Revenue	-0.05	0	-0.01	0.32	0			
7	Intangible	0.13	0.19	0.01	-0.34	-0.03	-0.1		
8	Return on assets	-0.01	-0.15	-0.02	0.02	-0.39	-0.05	0	
9	Growth	0.25	0.34	0.14	-0.11	1	0	-0.03	-0.39

Table 4. Main results

	Income-based efficiency			Sales based efficiency		
VARIABLES	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Blockchain	6.492***	5.799***	4.375**	36.15***	33.50***	22.68**
	(1.541)	(1.590)	(1.778)	(9.152)	(9.590)	(10.73)
Firm size		2.568	-1.308		-0.484	-19.84
		(4.324)	(2.848)		(26.08)	(20.02)
Leverage		-25.51**	-3.771		-52.52	26.13
		(10.01)	(8.244)		(60.40)	(54.48)
Revenue		1.219	0.774		26.64	22.51
		(4.156)	(3.314)		(25.06)	(22.27)
Intangible assets		-4.768	-0.503		-8.279	5.875
		(11.22)	(9.509)		(67.68)	(60.85)
Return on assets		57.64***	51.60***		7.578	-24.17
		(15.36)	(15.07)		(92.63)	(91.84)
Year effect	No	No	Yes	No	No	Yes
Industry effect	No	No	Yes	No	No	Yes
Constant	10.11***	-43.78	25.90	112.2***	-313.0	25.65
	(2.370)	(74.42)	(50.41)	(3.204)	(448.8)	(362.2)
Observations	507	507	507	507	507	507
R-squared	0.036	0.098	0.099	0.037	0.043	
Number of Firms	103	103	103	103	103	103

Standard errors are in parentheses
*** p<0.01, ** p<0.05, * p<0.1 denote statistical significance at 1%, 5% and 10% respectively
All variables are defined in Table 1

Table 5. Sectoral analysis

VARIABLES	Financial & Technology		Others	
	(1)	(2)	(3)	(4)
	Income	Sales	Income	Sales
Blockchain	10.36***	53.53***	0.250*	8.993
	(3.906)	(20.46)	(0.137)	(9.281)
Firm size	4.796	5.918	-0.438	-11.51
	(12.89)	(67.55)	(1.483)	(21.60)
Leverage	-54.03**	-191.0	-6.285*	-13.99
	(27.03)	(141.6)	(3.733)	(54.37)
Revenue	8.679	70.37	-0.515	17.52
	(13.07)	(68.49)	(1.399)	(20.37)
Intangible assets	8.688	156.0	-0.796	-15.90
	(44.35)	(232.3)	(3.556)	(51.79)
Return on assets	79.32	-278.2	44.85***	37.93
	(60.03)	(314.5)	(4.835)	(70.42)
Constant	-184.8	-1,041	22.99	-18.52
	(268.2)	(1,405)	(23.91)	(348.2)
Observations	185	185	322	322
R-squared	0.149	0.102	0.274	0.010
Number of Firms	38	38	65	65

Standard errors are in parentheses
*** p<0.01, ** p<0.05, * p<0.1 denote statistical significance at 1%, 5% and 10% respectively
All variables are defined in Table 1

Table 6: Accounting for growth opportunities

VARIABLES	Income-based		Sales based	
	(1)	**(2)**	**(3)**	**(4)**
Blockchain	5.781***	4.063**	33.50***	21.61**
	(1.591)	(1.767)	(9.603)	(10.72)
Growth	-1,368	-4,503***	-11.96	-17,635*
	(1,988)	(1,570)	(11,996)	(10,364)
Firm size	2.769	-0.942	-0.483	-18.03
	(4.337)	(2.834)	(26.17)	(20.03)
Leverage	1,345	4,502***	-40.53	17,680*
	(1,992)	(1,571)	(12,021)	(10,376)
Revenue	1.184	0.310	26.64	20.74
	(4.159)	(3.296)	(25.09)	(22.26)
Intangible assets	-3.705	2.118	-8.270	17.52
	(11.34)	(9.486)	(68.40)	(61.12)
Return on assets	61.30***	67.32***	7.610	29.78
	(16.26)	(15.93)	(98.13)	(96.93)
Year effect	No	Yes	No	Yes
Industry effect	No	Yes	No	Yes
Constant	-47.98	32.12	-313.0	37.26
	(74.72)	(50.17)	(450.9)	(362.0)
Observations	507	507	507	507
R-squared	0.099	0.104	0.043	0.062
Number of Firms	103	103	103	103

Standard errors are in parentheses
*** p<0.01, ** p<0.05, * p<0.1 denote statistical significance at 1%, 5% and 10% respectively
All variables are defined in Table 1

Table 7 Endogeneity checks

	PSM		DID	
VARIABLES	**Income-based**	**Sales based**	**Income-based**	**Sales based**
Blockchain	11.153**	76.064**		
	(4.710)	(38.786)		
Post*Treatment			3.161*	19.58*
			(1.905)	(11.34)
Treatment			8.201*	133.9***
			(4.446)	(33.15)
Post			2.812	25.80**
			(1.720)	(10.42)
Firm size	-0.0707	-0.0707	0.253	-7.269
	(0.0514)	(0.0514)	(1.732)	(13.72)
Leverage	0.952***	0.952***	-1.563	19.96
	(0.328)	(0.328)	(8.164)	(54.41)
Revenue	0.0335	0.0335	-1.518	5.621
	(0.0930)	(0.0930)	(2.675)	(19.34)
Intangible assets	-0.0227	-0.0227	4.043	32.83
	(0.331)	(0.331)	(7.744)	(52.32)
Return on assets			53.02***	-12.75
			(14.88)	(90.59)
Constant	-0.766	-0.766	26.53	65.61
	(1.651)	(1.651)	(48.46)	(347.7)
Observations	515	515	486	486
R-squared			0.087	0.118
Number of Firms			99	99

Standard errors are in parentheses
*** p<0.01, ** p<0.05, * p<0.1 denote statistical significance at 1%, 5% and 10% respectively
All variables are defined in Table 1