Do Users of Blockchain IT Infrastructure Value Environmental Sustainability? Evidence from Environmental Impact Disclosures

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May 17, 2024

Abstract

While the environmental impact has become an important IT governance agenda, it is unclear whether its disclosure is valued by token holders of platforms based on blockchain IT infrastructure and how platforms react to the changing public awareness of their environmental impacts. We consider Elon Musk's 2021 announcement that Tesla would suspend accepting Bitcoin as payment because of Bitcoin mining's environmental impact as a shock that dramatically increases awareness of Bitcoin mining's environmental impacts. We find that, after the shock, infrastructure platforms which have larger environmental impacts than application platforms, are more likely to disclose environmental impact information than application platforms and that their token market values grow at a slower rate, consistent with the increased awareness spills over to other token-based platforms. Furthermore, whereas pre-shock environmental impact disclosure by infrastructure platforms reduces token market value growth rates, post-shock disclosure has the opposite effect, consistent with green-costing and green-enhancing, respectively.

Keywords: token-based platform, IT infrastructure, awareness, environmental sustainability

1 Introduction

The governance of information technology (IT) infrastructure is an important topic, as IT infrastructures serve as the foundation for other IT applications (Xue et al., 2011). One aspect of such governance is assessing the impact of IT infrastructure on environmental sustainability. Despite its importance, this topic is rarely explored in the information systems (IS) literature (Melville, 2010). The current research aims to respond to the calls for new research on the managerial, organizational, and economic impact of blockchain IT infrastructure (Constantinides et al., 2018) by investigating the changes in environmental impact disclosure and the growth of token-based platforms following a shock that increases public's awareness of the environmental impact of Bitcoin, which thereby advances understanding of these platforms' responses to the token holders' shifting awareness of environmental sustainability issues.

Token-based platforms are digital platforms that secure asset ownership and facilitate transactions via digital tokens which are the fundamental units of asset ownership, value storage, and exchange (Cong and He, 2019), underpinning decentralized financial activities. By creating new tokens or leveraging existing tokens, these platforms integrate payments, asset trading, and other applications in an open blockchain infrastructure with little central control or regulation. Despite the significant role of token-based platforms in the digital economy and their surging economic impact, the existing literature does not clearly distinguish between types of token-based platforms that exert disparate degrees of environmental hazard. The current study delves into the heterogeneity of token-based platforms in the context of environmental impact.

Leveraging Elon Musk's May 2021 announcement regarding Tesla[1]'s suspension of accepting Bitcoin as payment because of Bitcoin mining's negative environmental impact ('the announcement') as an event study (online Appendix figure 1), we find that only seven

[1]Tesla (https://www.tesla.com) is one of the world's most valuable companies and, as of 2023, is the world's most valuable automaker. In 2022, the company led the battery electric vehicle market, with 18% share (source: Wikipedia).

platforms, each with a token market value at least US$300 million, had published their environmental impacts on web pages before the announcement (online Appendix figure 2 and table 1). However, the number increased by nearly 500% (to 34) after the announcement, between May 2021 and March 2023[2]. Such a dramatic change in disclosure level before and after the announcement offers a rare opportunity to study the effects of public awareness on the environmental impact disclosure of decentralized IT infrastructure as exemplified by token-based infrastructure platforms.

There seems to be no looming external regulatory pressure or internal motivation for platforms to deviate from existing disclosure practices unless they experience and respond to a major exogenous impact. First, there are no regulations that these platforms need to disclose environmental information. Unlike publicly traded companies, for which environmental impact disclosure have been proposed[3], token-based platforms are not subject to the same regulations. Second, platforms can disclose environmental information at a low cost because they primarily affect the environment through the energy consumption used in maintaining the digital platform. This usage can be derived from predetermined consensus algorithms and the computing difficulty in historical block verification (Ziolkowski et al., 2020). Our research question is as follows. *How has the increased public awareness of Bitcoin mining since the announcement influenced the environmental impact disclosure of token-based platforms and their token market value growth rates (TMVGRs)?* The token market value of token-based platforms is analogous to the capitalization in the stock market (Kogan et al., 2017), which equals the token price times circulating supply.

The literature presents competing views on the effects of environmental impact disclosure on platforms' TMVGRs. On the one hand, token-based platforms may be incentivized to voluntarily disclose information in an attempt to reduce information asymmetry and improve reputations (Howell et al., 2020), which we refer to as the 'green-enhancing effect'.

[2]Up to 2024 March, the number has become 68.

[3]For instance, the European Union's Non-Financial Reporting Directive requires certain companies to make environmental impact disclosures and expands the scope to 50,000 listed companies in 2023.

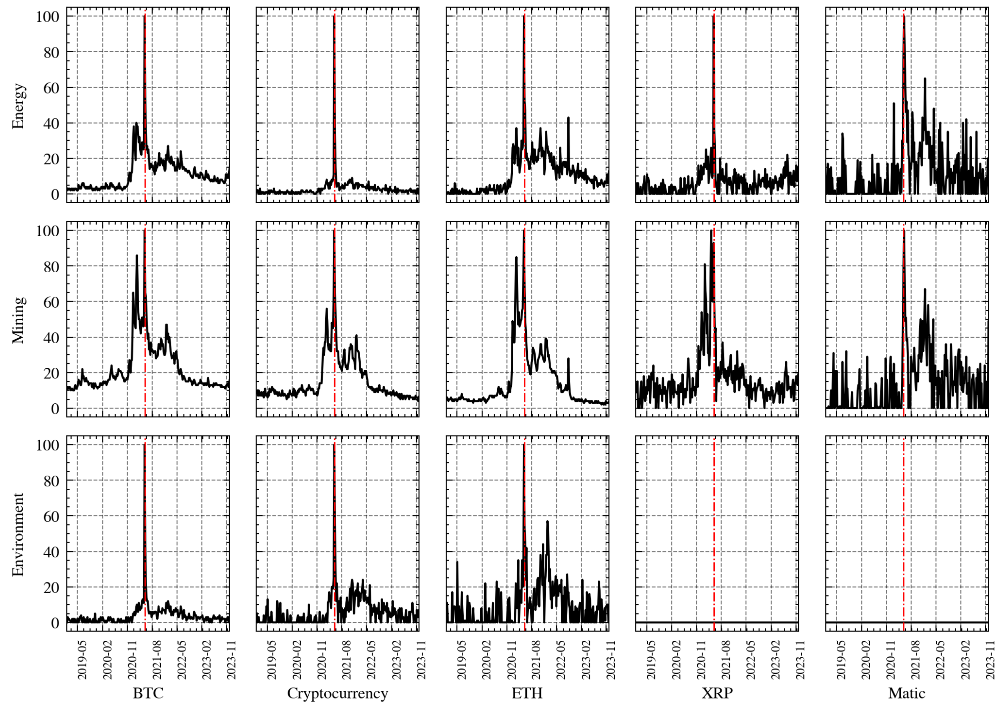

Figure 1: Weekly Google trends of worldwide search volume in cryptocurrency-related energy, mining, and environment from 2019 to 2023 (red lines: the announcement date)

On the other hand, such disclosures may be regarded as a waste of resources derived from agency problems between shareholders and managers (Krüger, 2015), and as diverting attention away from a platform's core business (Hirshleifer and Teoh, 2003). We refer to this negative effect as the 'green-costing effect'. In the current research, we examine whether the increased public awareness of Bitcoin mining's negative environmental impacts influences these two competing effects for token holders.

Our model-free evidence based on Google Trends shows the announcement brought significant public attention to the energy-consuming mining operations of Bitcoin, as shown in the sudden search volume increase of 'Bitcoin Environment' (Figure 1). Although the announcement only mentioned Bitcoin, we find that the public may become aware of the energy consumption of other token-based platforms and consider their environmental implications, suggesting an **'awareness spillover effect'**.

We classify token-based platforms into two types based on their operations (Figure 2):

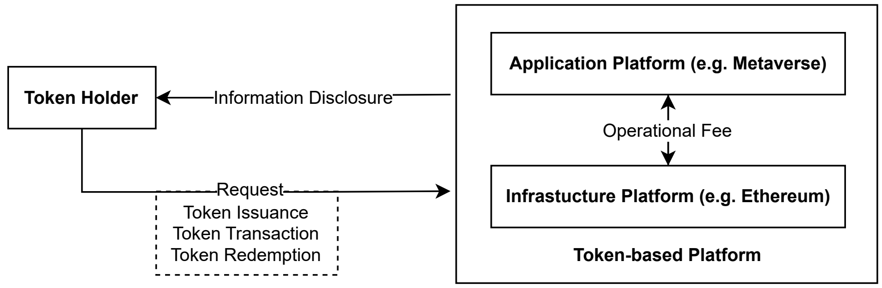

Figure 2: Layered Structure for Token-based Platforms

(1) **infrastructure platforms (IPs)**, such as Ethereum[4], which continually expands the blockchain length through the mining of new blocks; and (2) **application platforms (APs)**, such as Sandbox[5], which do not have their own blockchain but create their contracts and issue tokens on IPs.

We expect that the spillover of public awareness to be more intensive toward IPs than APs, as only IPs directly engage in energy-intensive mining. We first study how the increased public awareness of Bitcoin mining's environmental impacts influenced the TMVGRs of IPs and APs. Our results show that after the awareness increases, IPs' TMVGRs decrease more than those of APs. We then investigate whether the increased public awareness leads to more environmental impact disclosures. We focus on environmental web pages as they serve as vital information sources for token holders to understand the operation and performance of a platform (Lynch and Taylor, 2021). As expected, we find a significant increase in environmental web pages launched by IPs, but not by APs, after the shock.

Both pieces of evidence are consistent with that a spillover of awareness on energy consumption of Bitcoin influences the IPs and their token holders. We also study whether environmental impact disclosures by IPs can mitigate the awareness spillover and find that IPs' TMVGRs significantly increase after their disclosures. To mitigate the concern that

[4]Ethereum (https://ethereum.org) is a decentralized blockchain with smart contract functionality. Among cryptocurrencies, ether is second only to bitcoin in market capitalization (source: Wikipedia).

[5]Sandbox (https://www.sandbox.game/), a Metaverse token-based platform built on Ethereum and Polygon, issues a fungible token called Sand for circulation.

publishing any web page could increase a platform's TMVGR, we conduct a falsification test using social pages and find null results, consistent with the increase in TMVGR driven by environmental impact disclosure. Finally, we show that before the shock, IPs' TMVGRs decrease after their web page environmental impact disclosure. Taken together with our earlier evidence on the positive effect of environmental disclosure on TMVGR after the shock, we conclude that the awareness spillover moderates the green-costing effect of these disclosures.

Our work contributes to the literature in several aspects. First, we contribute to the discussion of IT infrastructure governance by showing that IT environmental sustainability awareness can significantly influence the disclosure practices of infrastructure platforms. In response to the call for blockchain IT infrastructure governance (Constantinides et al., 2018), we differentiate IT infrastructure and IT applications from token-based platforms by demonstrating their differential reaction to the spillover of awareness of mining's environmental impact.

Second, our study contributes to the environmental sustainability in IS by assessing outcomes of environmental impact disclosure (Melville, 2010). Most studies focus on green IS conceptualization (Malhotra et al., 2013; Seidel et al., 2013), and effects measurement (Leidner et al., 2022; Saldanha et al., 2022), but analyses of the green effect trade-off are scant. The most closely related empirical study (Hu et al., 2016) shows that contextual factors, such as the general public's awareness, correlate with adopting these practices. Our study, however, differs by investigating awareness's moderating effect on the trade-off between green-costing and green-enhancing effects from a longitudinal perspective.

Third, the token literature explores theoretical models of tokens (Chod and Lyandres, 2021; Cong and He, 2019; Sockin and Xiong, 2023), initial coin offerings (ICOs) (Howell et al., 2020; Malinova and Park, 2023), mining scalability (Cong et al., 2023), and conflict resolution (Bakos and Halaburda, 2022; Gudmundsson et al., 2024). The most closely related study (Bourveau et al., 2022) explores the impact of voluntary disclosure on ICO success. However, our research differs by focusing on environmental impact disclosure data, and these disclosures often happen in the post-ICO period. Besides, we improve the empirical methodology of token studies by emphasizing the need to control for omitted operational cost variables to make IPs and APs comparable.

Lastly, we contribute to the corporate social responsibility (CSR) literature on legitimacy theory (Cho and Patten, 2007). Few empirical studies provide consistent support for its argument that public pressure can influence the extent of CSR disclosure, because companies may anticipate that such social pressure will lead to later regulatory requirements (Fiechter et al., 2022; Michelon et al., 2020). Given the setting that token-based platforms have no regulatory need to disclose environmental impact information, we show that social pressure itself can influence the extent of their environmental impact disclosure.

2 Research Background

We first introduce the terminology used in this study and then discuss the literature on IT infrastructure governance, digital environmental sustainability, and voluntary disclosure.

2.1 Terminology

Blockchain and tokens are integral components of digital platforms (Hendershott et al., 2021). **Blockchain** can securely and consistently record and verify data across a decentralized network (Cho et al., 2021; Liang et al., 2021). Blockchain functions as a database (Constantinides et al., 2018), which has great utility when recording data of token ownership changes (Chen et al., 2023). Token-based platforms in this study are based on the public blockchain that enables anyone to view and submit transactions (Ziolkowski et al., 2020). **Token** functions as a digital identifier that represents ownership of both virtual and physical assets (Ziolkowski et al., 2020). Tokens can be registered on any database (Bauer et al., 2022), including non-blockchain databases, although registering in blockchain can facilitate the transfer of tokens across a decentralized network.

2.2 IT Infrastructure Governance

IT infrastructures serve as the foundation for other IT applications (Xue et al., 2011; Tiwana and Kim, 2015). The governance of infrastructure and applications requires different knowledge (Tiwana and Kim, 2015). Therefore, clearly differentiating infrastructure and application is important. Traditional IT services have a clear differentiation between infrastructure (Xue et al., 2011) and applications (Brown and Magill, 1994, 1998; Tiwana and Kim, 2015). However, the literature on discussing blockchain IT infrastructure and application is scarce.

Based on the market nature, we differentiate token-based platforms into two types: **infrastructure platforms (IPs)** and **application platforms (APs)**. IPs are digital platforms that provide the infrastructure layer of the blockchain that requires mining to validate transactions and generate new blocks (Basu et al., 2023). APs, in contrast, provide services by leveraging decentralized blockchain data recording services provided by IPs. APs are less reliant on mining than IPs, but they pay operation fees to IPs for their services (Ziolkowski et al., 2020). For example, Metaverse token-based platforms, such as Sandbox[6], can be classified as APs, as they rely on IPs for token issuance, transaction, and redemption, such as DAO applications (Ellinger et al., 2024). Recent studies also show similar market structure explorations, indicating that token-based platforms have digital platforms of the infrastructure layer and the application layer (Chen et al., 2021).

Despite the differences between IPs and APs, we find that they have strong interdependence relationships where APs rely on IPs to provide services. These interdependent relationships make both digital platforms not comparable when studying their performance. Prior studies that do not consider the interdependence relationships between IPs and APs may suffer from omitted variable bias Liu and Tsyvinski (2021); Davydiuk et al. (2023).

[6]https://www.sandbox.game/

Considering the broad unawareness of the layered structure of token-based platforms, our study aims to uncover the layered structure and the interdependence relationships between IPs and APs by showing their different environmental sustainability practices.
Within the public blockchain, the environmental impacts of IPs and APs can be measured by the reactions of token holders (Xie et al., 2020). Unlike traditional IT systems, where infrastructure and applications are intertwined and a consistent measure of user reactions to both platforms is scarce, the blockchain setting has tokens representing both IT infrastructure and applications which are traded independently. The reactions of users are reflected via tokens for both IPs and APs, which offers a distinctive opportunity to examine the varied responses to environmental impact disclosures of token-based platforms.

2.3 Digital Environmental Sustainability

The intersection of digital technology and environmental sustainability has become a prominent topic in IS research (Kotlarsky et al., 2023; Malhotra et al., 2013; Melville, 2010). Prior studies have focused on environmental sustainability in traditional, centralized organizations (Dedrick, 2010; vom Brocke et al., 2013). Conversely, the specific environmental implications of blockchain technology, an emergent tech, have yet to be thoroughly empirically investigated (Kotlarsky et al., 2023). Our research addresses this gap by providing an empirical analysis of environmental impact disclosures associated with decentralized IT infrastructures and applications.
Green IT studies have explored the drivers for the adoption of IS sustainable solutions, particularly at the centralized organizational level, focusing on issues concerning awareness of IT's impact on the environment (Hu et al., 2016). Our study shows that the awareness of bitcoin mining's environmental impacts spills over to other token-based platforms, leading to more environmental impact disclosures by token-based platforms. However, we find that such awareness only motivates IPs, rather than APs, to publish environmental impact disclosures. We also find that awareness has a significantly negative impact on the token

market value growth rates of IPs and APs. The effect is more pronounced for infrastructure platforms than application platforms.

2.4 Voluntary Disclosure

Legitimacy theory (Cho and Patten, 2007) suggests public pressure can influence the extent of CSR disclosure. However, few empirical studies provide consistent support for its argument because companies may anticipate that such social pressure will lead to later regulatory requirements (Fiechter et al., 2022; Michelon et al., 2020). Our study shows that in the less-regulated market, more token-based platforms disclose environmental information after the increase in public awareness, suggesting that social pressure itself can influence the extent of their environmental impact disclosure.

Environmental impact disclosure has competing effects. Token-based platforms may be incentivized to voluntarily disclose information to reduce information asymmetry and improve reputations (Howell et al., 2020), a phenomenon we refer to as the green-enhancing effect'. (Howell et al., 2020) documents that the success of ICOs is positively associated with the extent of voluntary disclosure by providing quality signals to potential investors. Conversely, such disclosures may be perceived as a waste of resources stemming from agency problems between shareholders and managers (Krüger, 2015) and as diverting attention away from a platform's core business (Hirshleifer and Teoh, 2003). We refer to this negative effect as the green-costing effect'. The argument is that CSR primarily benefits managers who, at the expense of shareholders, earn a good reputation among key stakeholders (Krüger, 2015). Moreover, a study on Robinhood investors also shows that retail investors do not respond to environmental impact disclosures (Moss et al., 2023).

Considering the uncertain effects in responses to environmental impact disclosures in the literature, our research reveals that the awareness moderates the green effect of infrastructure platforms' environmental impact disclosures such that the green effect is negative before the awareness and positive after the awareness.

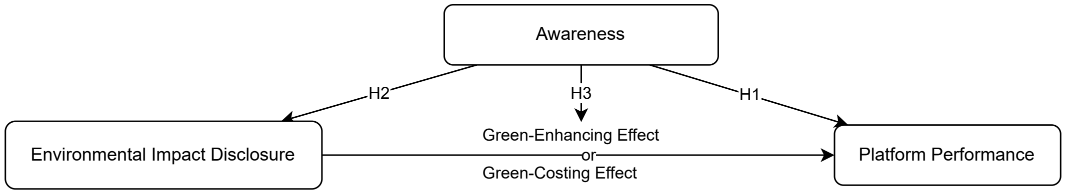

Figure 3: Research Model

3 Hypothesis Development

Figure 3 shows our research model. We examine whether the public awareness of Bitcoin mining's environmental impacts influences the environmental impact disclosure of token-based platforms and their TMVGRs. The token market value changes through two channels: token supply fluctuations (including new token issuance and token redemption) and buy/sell transactions on the secondary market where token price depends on the transaction demand (Cong et al., 2021). We measure platform performance via TMVGR rather than price return because the token supply is highly dynamic and price cannot reflect token issuance and token redemption activities timely (Sockin and Xiong, 2023). Token issuance and redemption reflect the adoption and disadoption of token-based platforms, respectively. Token transactions reflect the token utility, which determines its price in secondary markets (Cong et al., 2021). Overall, TMVGR can measure the performance change in token issuance, redemption, and transaction demand. We also use price change and supply change as dependent variables as references (Liu et al., 2022).

The awareness of Bitcoin mining's impact is likely to spill over to the awareness of mining's energy consumption of other IPs. Given the positive role of awareness (Hu et al., 2016), we hypothesize that the awareness of Bitcoin mining's environmental impacts decreases the TMVGRs of token-based platforms. Given the layerd structure between IPs and APs, the effect is more pronounced for IPs than APs.

Hypothesis 1: *The awareness of Bitcoin mining's environmental impacts decreases the TMVGRs of IPs, but not APs.*

Platforms are expected to disclose relevant information to alleviate concerns about mining and meet the expectations of token holders (Cho and Patten, 2007). Given that only IPs are directly involved in mining, we propose the following hypothesis:

Hypothesis 2: *The awareness of Bitcoin mining's environmental impacts leads IPs to disclose more environmental impact information than APs.*

Environmental impact disclosures can exert two opposing effects on platform performance: (1) a green-enhancing effect due to potential quality signals (Howell et al., 2020), or 2) a green-costing effect due to potentially unprofitable actions (Krüger, 2015). As suggested by Hypothesis 1, IPs may experience a decrease in TMVGRs due to their perceived negative environmental impacts, which indicates that the token holders have a net green-enhancing viewpoint. In contrast, before the awareness, environmental impact disclosure may be viewed as unprofitable (Krüger, 2015), because only a few platforms have disclosed environmental information or because token holders are indifferent to potential negative environmental impacts (Aswani et al., 2024; Moss et al., 2023). Thus, to test the moderating role of the awareness, we propose the following hypothesis:

Hypothesis 3: *The awareness moderates the green effect of IPs' environmental impact disclosures such that the green effect is negative (positive) before (after) the awareness.*

4 Data and Statistical Summary

4.1 Financial Panel Data

We collect financial data of the study platforms from Coinmarketcap[7], focusing on token-based platforms with a token market value of at least US$100 million[8]. To examine the

[7]CoinMarketCap (https://coinmarketcap.com/) reports secondary market data for thousands of tokens and is generally perceived to be the highest-quality source for such data.

[8]The token market value of one platform can be converted to USD according to its token price and supply.

impact of the shock on 12 May 2021, we focus on 12 April to 12 June 2021. Certain platforms are too small to have marketcap data. We exclude them in our baseline dataset. Our baseline data consists of over 300 distinct platforms (125 IPs and 222 APs), totaling 20,199 platform-day observations. We exclude Bitcoin because of its direct involvement in Elon Musk's announcement, as token holders' reactions could stem from Bitcoin's decreased payment utility rather than its environmental implications. We also exclude stablecoin platforms to avoid endogeneity concerns, because the TMVGRs of both IPs and APs influence the TMVGRs of stablecoin platforms. Most stablecoin platforms serve as a bridge between fiat currencies and digital tokens, including IP and AP tokens.

4.2 Web Page Data

Platform web pages inform token holders of platforms' mission, strategies, and operation (Bourveau et al., 2022), which often share similar designs, allowing for categorization. We manually collect 2,600 web pages from the top 200 token-based platforms (stablecoin platforms are excluded) by market capitalization as of April 1, 2023, and categorize them into eight distinct types[9]. We utilize the Wayback Machine[10] and extract the first archived date for each page, as the earliest page reflects the primary change in environmental impact disclosure and has the largest impact on token holders, as compared with later complementary disclosures. Our dataset comprises 2,382 unique pages, excluding pages that are not archived by the Wayback Machine. Considering the Wayback Machine's indexing delay, we verify launch dates with corresponding environmental news reports to ensure the precision of our data.

To study the post-shock green effects, we create a panel that incorporates 79 IPs, of which 41 have environmental web pages. We remove Bitcoin and five IPs with environmental web pages published before 12 May 2021. The final after-shock panel data consists of 39,430

[9]For the classification of the 'Environmental' and 'Social' content, we followed the ESG (Environmental, Social, Governance) definitions provided by the U.S. Securities and Exchange Commission (US SEC).

[10]Wayback Machine (http://archive.org/web/) is an online archive of past instances of websites.

observations spanning 12 May to 1 March 2023. To study the pre-shock green effect, we find five IPs – EOS, XRP, ALGO, HOT, and NEAR – with published environmental web pages before 12 May 2021. Two platforms (CSPR and MOB) are excluded as their financial data start 6 months after their environmental page publication. The final all-period panel data comprises 63,211 observations.

4.3 Statistical Summary

Table 1 describes three primary datasets. The dependent variable TMVGR has an average value close to 0, but its minimum and maximum values are large, indicating significant reactions from token holders during this period. We use the log difference to calculate TMVGRs, achieving a balanced magnitude between maximum negative and maximum positive TMVGRs. The control variables include prior volume and prior volume over marketcap. We exclude data points if the value of any control variable is missing.

In the baseline data, the explanatory variable '$PostShock$' has an average value of 0.54, implying a balance of observations between the pre-shock period and post-shock periods. In the IP panel data, '$Post$' has a mean of 0.06, meaning that only a small proportion of the dataset's observations come from the post-disclosure period because we include all data from the pre-disclosure period and 3 months of data from the post-disclosure period. For heterogeneous variables, we include two indicators of the degree of regulation (defined in Appendix A).

5 Empirical Strategies and Results

5.1 Difference-in-Difference

We use a difference-in-difference (DID) approach (model 1) with APs as the control group and IPs as the treatment group. Before running regressions, we plot the model-free evidence. We control for the entity-level fixed effects and year-by-month-by-day fixed effects

Table 1: Statistics Summary

Sub table 1: Baseline Statistics

Time FE	count	mean	std	min	25%	50%	75%	max
$TMVGR_{it}$	20,199.0	-0.01	0.12	-2.18	-0.07	-0.01	0.04	1.99
$return_{it}$	20,199.0	-0.01	0.12	-2.18	-0.07	-0.01	0.04	1.99
$supplyChange_{it}$	20,199.0	0.0	0.03	-0.38	-0.0	0.0	0.0	1.56
$postShock_{it}$	20,199.0	0.54	0.5	0.0	0.0	1.0	1.0	1.0
IP_i	20,199.0	0.37	0.48	0.0	0.0	0.0	1.0	1.0
$volumeOverMcap_{i,t-1}$	20,199.0	0.19	0.66	0.0	0.02	0.07	0.18	27.88
$volume_{i,t-1}$	20,199.0	428.08	2,779.26	0.0	2.56	15.45	98.87	84,482.91
pow_i	20,199.0	0.07	0.25	0.0	0.0	0.0	0.0	1.0

Sub table 2: Staggered Adoption with Both Before- and After-Shock Periods

Time FE	count	mean	std	min	25%	50%	75%	max
$TMVGR_{it}$	63,211.0	0.0	0.07	-1.44	-0.03	0.0	0.03	1.93
$return_{it}$	63,211.0	-0.0	0.08	-5.55	-0.03	-0.0	0.03	1.52
$supplyChange_{it}$	63,211.0	0.0	0.03	-0.52	-0.0	0.0	0.0	4.49
$post_{it}$	63,211.0	0.05	0.21	0.0	0.0	0.0	0.0	1.0
$preShock_i$	63,211.0	0.36	0.48	0.0	0.0	0.0	1.0	1.0
$address_i$	63,211.0	0.41	0.49	0.0	0.0	0.0	1.0	1.0
$registered_i$	63,211.0	0.46	0.5	0.0	0.0	0.0	1.0	1.0
$weekReturn_{i,t-1}$	63,211.0	-0.0	0.23	-13.54	-0.09	-0.0	0.08	2.3
$monthReturn_{i,t-1}$	63,211.0	-0.0	0.51	-13.7	-0.22	-0.02	0.19	2.58
$3MonthReturn_{i,t-1}$	63,211.0	-0.02	0.96	-14.42	-0.49	-0.1	0.36	3.88
$mCap_{i,t-1}$	63,211.0	6,208.68	30,114.85	1.97	277.95	895.33	3,117.37	569,094.33

Notes: Market Capitalization (MCap) is expressed in millions.

to capture unobserved platform characteristics and macro time trends. Figure 4 shows the TMVGRs of IPs and APs before and after the shock. Both IPs and APs exhibit a similar trend before the shock. After the shock, both IPs and APs decrease dramatically, but IPs decrease more than APs. Because of the interdependence between IPs and APs, IPs are directly impacted by the shock, while APs are indirectly impacted. Thus, we expect the TMVGRs of IPs to decrease more than those of APs after the shock.

Hypothesis 1 suggests that after the awareness increases, the TMVGRs of treated units (IPs) decrease more than those of control units (APs). Although both IPs and APs are token-based platforms, APs necessitate the payment of fees to function on IPs, creating a dependence of APs on IPs. Thus, to make IPs and APs comparable, we incorporate the

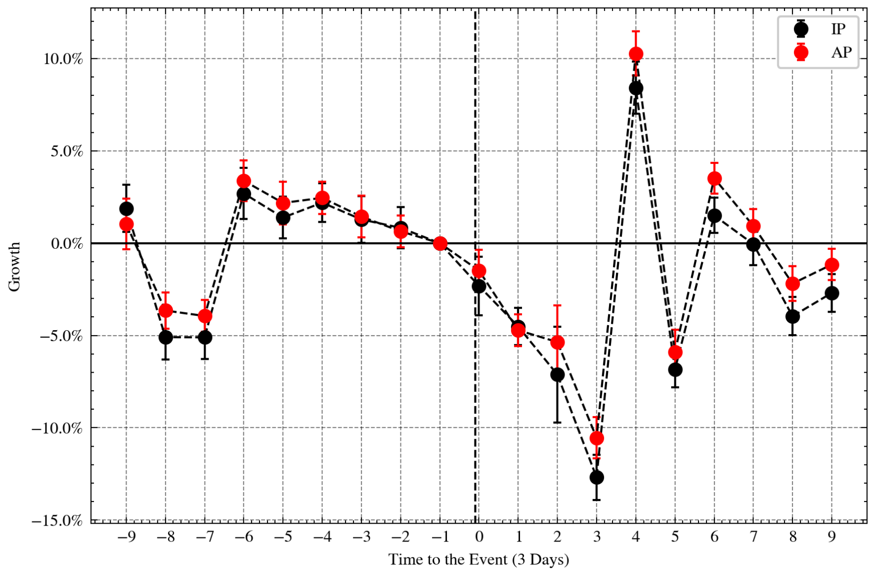

Figure 4: Model free evidence of the event shock on IP and AP with fixed effects

volume and volume over marketcap of IP tokens as control variables because they are directly correlated with the service demand of APs. We further check the parallel trend assumption. Model 2 explores the dynamics of the treatment effects within the preceding and subsequent 30 days.

$$Y_{it} = \alpha_i + \delta_t + \beta \times postShock_t \times IP_i + control_{i,t-1} + \epsilon_{i,t} \tag{1}$$

$$Y_{it} = \alpha_i + \delta_t + \sum_{k=-10,k\neq-1}^{10} \beta_{k(t)} \times IP_i + control_{i,t-1} + \epsilon_{i,t} \tag{2}$$

where Y_{it} represents the TMVGR for platform i in day t. $Control_{i,t-1}$ includes various time series control variables. To address concerns regarding unobserved endogenous platform characteristics and macro trends across distinct temporal periods, we incorporate both platform-level fixed effects α_i and year-by-month-by-day fixed effects δ_t. The platform-fixed effects can capture unobserved platform characteristics, and the time-fixed effects capture macro-time trends each day. $Post_t$ and IP_i are absorbed by the fixed effects as they are unit-invariant or time-invariant. $\beta_{k(t)}$ and IP_i are absorbed by fixed effects as they are unit-invariant or time-invariant.

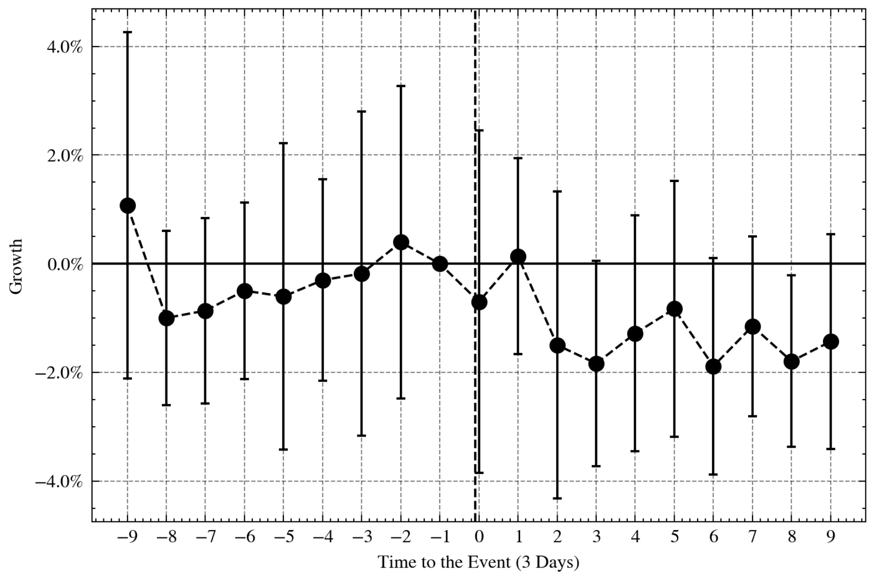

Figure 5: Estimated Effects of the Awareness on the TMVGRs of Token-Based Platforms

Table 2 indicates that after the shock, IPs' TMVGRs decrease more than those of APs. The entity-clustered standard error provides a more precise result. According to columns (1) and (4), after the shock, IPs' TMVGRs decrease more than those of APs by 0.61% on average. This effect becomes more salient after controlling other factors influencing IPs' TMVGRs, as shown by 1.00% in columns (2). We use return and supply change as additional dependent variables and only return has similar results. We report the results of model 2 in the online Appendix table 2 and figure 5, which suggest no significant difference between the treatment group and control group during the pre-shock period, indicating the comparability between the treatment group (IPs) and the control group (APs) before the shock. Thus, Hypothesis 1 is supported.

5.2 Chi-Square Test

We use the chi-square test to assess the statistical significance of the change in the number of environmental impact disclosures between the pre- and post-shock periods. Table 3 suggests a significant increase in the number of IPs, not APs, that published environmental web pages. Before the awareness increases, only seven IPs published environmental web

Table 2: Impact of Event Shock on IPs' and APs' TMVGRs

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Variable	$TMVGR_{it}$	$TMVGR_{it}$	$return_{it}$	$return_{it}$	$supplyChange_{it}$	$supplyChange_{it}$
No. Observations	20,199	20,199	20,199	20,199	20,199	20,199
Cov. Est.	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
R-squared	0.0003	0.0028	0.0003	0.0030	2.252e-06	4.452e-05
R-Squared (Within)	0.0017	0.0056	0.0018	0.0058	-2.109e-05	-1.135e-05
Intercept	-0.0080***	0.0781***	-0.0090***	0.0765***	0.0010***	0.0016
	(0.0004)	(0.0178)	(0.0004)	(0.0176)	(0.0001)	(0.0026)
$postShock_{it}$:IP_i	-0.0061***	-0.0100***	-0.0059***	-0.0099***	-0.0002	-0.0001
	(0.0023)	(0.0029)	(0.0022)	(0.0028)	(0.0006)	(0.0007)
$\log(IP_i : volume_{i,t-1})$		-0.0139***		-0.0138***		-0.0001
		(0.0029)		(0.0028)		(0.0004)
$\log(IP_i : volumeOverMcap_{i,t-1})$		0.0624**		0.0585**		0.0039**
		(0.0265)		(0.0263)		(0.0018)
Entity FE	○	○	○	○	○	○
Time FE	○	○	○	○	○	○

Notes: The table reports the estimated coefficients (β) from Model 1 investigating the differential impact of the event shock on the TMVGRs of IP and AP. Entries in parentheses below the coefficient estimates are standard errors. Each column represents a different model variation with distinct control variables or estimation methods. 'Clustered' standard error groups at the platform level. 'Time Trend Control' includes prior week return, prior month return, and prior three-month return. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

Table 3: Number of Environmental Web Pages Published Before and After the Awareness Increase

IP	Published	Not Published	Total
Before Increase	7	78	85
After Increase	34	51	85
Total	41	130	170
AP	Published	Not Published	Total
Before Increase	0	105	105
After Increase	0	105	105
Total	0	210	210

pages over three years. After the awareness, the number of IPs publishing environmental web pages dramatically increased by 500% within eighteen months. The Chi-square statistic is computed as: $\chi^2 = \frac{(7-16.65)^2}{16.65} + \frac{(78-68.35)^2}{68.35} + \frac{(34-24.35)^2}{24.35} + \frac{(51-60.65)^2}{60.65} = 8.36$. The critical value for a significance level of 0.01 is 6.63 (freedom = 1). As the calculated chi-square value, 8.36, is greater than the critical value, we reject the null hypothesis that there is no significant increase in the number of environmental web pages published by IPs after the awareness increases. For APs, however, because no environmental web pages were published before or after the awareness increases, no change in behavior is observed. The pre-shock period is much longer than the post-shock period. We expect that if we keep period lengths the same, the contrast will become even more salient. Thus, Hypothesis 2 is supported.

5.3 Staggered Adoption Difference-in-Difference

We use IP panel data to study the effect of environmental impact disclosure on IPs' TMVGRs (green effect). Because platforms publish environmental web pages at different time points, we employ a staggered adoption DID model, model 3, to test the green effects. Our two-way fixed-effects model compares the differences in IPs' TMVGRs between the control and treatment groups before and after environmental impact disclosure. The control

group consists of platforms that have not yet published environmental web pages, whereas the treatment group consists of platforms that have published environmental web pages.
To compare the heterogeneous periods, we use another staggered adoption DID regression model, model 4 with a heterogeneous time variable $preShock_t$. Model 3 and 4 are presented as follows:

$$Y_{it} = \alpha_i + \delta_t + \beta \times post_{it} + control_{i,t-1} + \epsilon_{i,t} \tag{3}$$

$$Y_{it} = \alpha_i + \delta_t + \beta \times preShock_t \times post_{it} + \gamma_1 \times post_{it} + control_{i,t-1} + \epsilon_{i,t} \tag{4}$$

where Y_{it} represents TMVGRs of platform i in day t. $Post_{it}$ represents the web page launch dummy variable for platform i on day t. Similar to model 1, we incorporate both platform-level fixed effects α_i and year-by-month-by-day fixed effects δ_t. $PreShock_t$ is a dummy indicator showing whether the time is before the shock, which is absorbed by the fixed effects as it is unit-invariant.
Table 4 presents the estimation results for model 3. Columns (1) and (2) show that after the web page environmental impact disclosure, IPs' TMVGRs increase by 0.24% on average. We also include the other two dependent variables and the results show the change in marketcap is mainly driven by price change. Figure 6 shows the parallel trend of the treatment and control groups.
Table 5 presents the estimation results for model 4, showing the awareness moderates the green effect. Column (1) and (2) show that the increased public awareness increases the effect by 0.89%. During the pre-shock period, IPs' TMVGRs decrease by 0.63% on average (0.26%–0.89%) after web page environmental impact disclosures. In columns (5) and (6), the estimates have a similar significance level, suggesting that the awareness increases the effect by 0.99% and 0.98%, respectively. We find evidence for the green-costing effect during the pre-shock period, and the increased public awareness dramatically increases this green effect. Thus, hypothesis 3 is supported.

Table 4: Effects of Web Page Environmental Impact Disclosures on IPs' TMVGRs

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Variable	$TMVGR_{it}$	$TMVGR_{it}$	$return_{it}$	$return_{it}$	$supplyChange_{it}$	$supplyChange_{it}$
No. Observations	39,430	39,430	39,430	39,430	39,430	39,430
Cov. Est.	Robust	Clustered	Robust	Clustered	Robust	Clustered
R-squared	0.0039	0.0039	0.0168	0.0168	0.0416	0.0416
R-Squared (Within)	0.0028	0.0028	0.0106	0.0106	0.0307	0.0307
Intercept	0.0507***	0.0507***	0.0482***	0.0482***	0.0026	0.0026
	(0.0077)	(0.0079)	(0.0078)	(0.0066)	(0.0033)	(0.0040)
$post_{it}$	0.0024**	0.0024**	0.0021*	0.0021*	0.0003	0.0003
	(0.0012)	(0.0012)	(0.0011)	(0.0011)	(0.0005)	(0.0003)
$\log(mCap_{i,t-1})$	-0.0073***	-0.0073***	-0.0070***	-0.0070***	-0.0003	-0.0003
	(0.0011)	(0.0011)	(0.0011)	(0.0009)	(0.0004)	(0.0006)
$weekReturn_{i,t-1}$	0.0010	0.0010	0.0369	0.0369***	-0.0359	-0.0359**
	(0.0143)	(0.0052)	(0.0298)	(0.0122)	(0.0250)	(0.0162)
$monthReturn_{i,t-1}$	0.0029	0.0029***	0.0013	0.0013	0.0015	0.0015**
	(0.0020)	(0.0005)	(0.0023)	(0.0011)	(0.0011)	(0.0007)
$3MonthReturn_{i,t-1}$	0.0003	0.0003	-0.0003	-0.0003	0.0006*	0.0006***
	(0.0008)	(0.0004)	(0.0009)	(0.0003)	(0.0003)	(0.0002)
Entity FE	◯	◯	◯	◯	◯	◯
Time FE	◯	◯	◯	◯	◯	◯

Notes: This table reports the results of a staggered adoption DID study of model 3 and 4, examining the effects of environmental impact disclosure on IPs' TMVGRs. Entries in parentheses below the coefficient estimates are 'Clustered' standard error grouping at the platform level. 'Time Trend Control' includes prior week return, prior month return, and prior three-month return. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

Table 5: Effects of Web Page Environmental Impact Disclosures on IPs' TMVGRs

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Variable	$TMVGR_{it}$	$TMVGR_{it}$	$return_{it}$	$return_{it}$	$supplyChange_{it}$	$supplyChange_{it}$
No. Observations	63,211	63,211	63,211	63,211	63,211	63,211
Cov. Est.	Robust	Clustered	Robust	Clustered	Robust	Clustered
R-squared	0.0025	0.0025	0.0098	0.0098	0.0282	0.0282
R-Squared (Within)	0.0019	0.0019	0.0069	0.0069	0.0179	0.0179
Intercept	0.0283***	0.0283***	0.0258***	0.0258***	0.0025	0.0025
	(0.0036)	(0.0034)	(0.0033)	(0.0034)	(0.0022)	(0.0019)
$post_{it}$:$preShock_i$	-0.0089**	-0.0089***	-0.0077*	-0.0077***	-0.0012	-0.0012*
	(0.0043)	(0.0021)	(0.0044)	(0.0018)	(0.0009)	(0.0007)
$post_{it}$	0.0026**	0.0026***	0.0026**	0.0026***	3.37e-06	3.37e-06
	(0.0011)	(0.0009)	(0.0010)	(0.0009)	(0.0004)	(0.0003)
$\log(mCap_{i,t-1})$	-0.0040***	-0.0040***	-0.0037***	-0.0037***	-0.0002	-0.0002
	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0003)	(0.0003)
$weekReturn_{i,t-1}$	0.0019	0.0019	0.0290	0.0290**	-0.0271	-0.0271*
	(0.0109)	(0.0040)	(0.0223)	(0.0127)	(0.0189)	(0.0155)
$monthReturn_{i,t-1}$	0.0027*	0.0027***	0.0017	0.0017*	0.0010	0.0010*
	(0.0016)	(0.0005)	(0.0018)	(0.0010)	(0.0007)	(0.0006)
$3MonthReturn_{i,t-1}$	-0.0007	-0.0007*	-0.0010	-0.0010**	0.0002	0.0002***
	(0.0007)	(0.0004)	(0.0007)	(0.0004)	(0.0002)	(7.144e-05)
Entity FE	○	○	○	○	○	○
Time FE	○	○	○	○	○	○

Notes: This table reports the results of a staggered adoption DID study of 4, examining the effects of environmental impact disclosure on IPs' TMVGRs. Entries in parentheses below the coefficient estimates are 'Clustered' standard error grouping at the platform level. 'Time Trend Control' includes prior week return, prior month return, and prior three-month return. *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

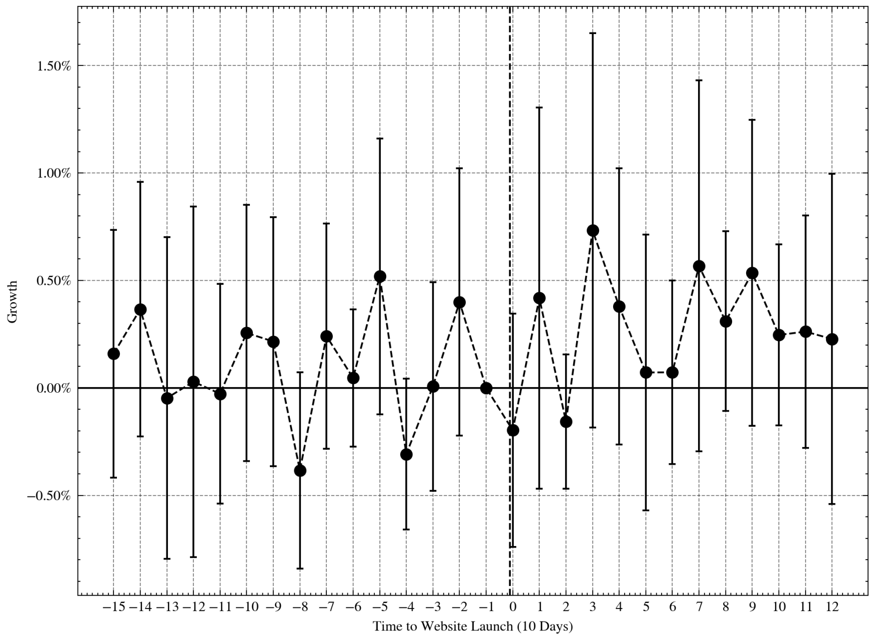

Figure 6: Estimated Effects of the Environmental Impacts Disclosure on the TMVGRs of Token-Based Platforms After the Shock (1% significance level)

5.4 Falsification Check and Heterogeneous Effect Test

To mitigate concerns that any web page would increase a platform's TMVGR, we conduct a falsification check with social pages, as social pages are also ESG[11]-related pages and thus comparable to environmental pages. We find that social pages have null effects compared with environmental pages during the post-shock period (Table 6).

Regulation lags behind the development of these platforms, resulting in financial woes that have recently appeared in media headlines[12]. We verify the absence of regulatory concerns within the token market by studying heterogeneous platform's legal status. We construct two variables to indicate the degree of regulation: *Registration* and *Address* (defined in Appendix A). If regulatory intensity did play a role, platforms subject to stricter regulation would benefit from such disclosures more than other platforms because of their compliance requirements. We find that different degrees of regulation do not have significantly

[11]Environmental, social, and governance.

[12]For instance, the crash of Luna is estimated that $60 billion got wiped out of the digital currency space (Forbes).

different green effects (Table 6), which aligns with the argument that in loosely regulated markets, investors tend to disregard regulatory risks (Ilhan et al., 2021).

5.5 Extension

IPs have different consensus algorithms, which can lead to different environmental impacts. On average, the proof-of-work (pow) consensus algorithm has more severe environmental impacts (Mora et al., 2018; Wendl et al., 2023). Therefore, we construct pow_i as an indicator to see whether pow-based IPs have more severe reactions from users. Our empirical model is as follows:

$$Y_{it} = \alpha_i + \delta_t + \beta \times postShock_t \times IP_i \times pow_i + control_{i,t-1} + \epsilon_{i,t} \tag{5}$$

where Y_{it} represents the TMVGR, return, and supply changes for platform i in day t. pow_i indicates whether an IP i uses proof-of-work consensus algorithm. $Control_{i,t-1}$ includes various time series control variables. Other variables are the same as model 1.

Our result shows that pow-based IPs have a more significant decrease in TMVGRs than non-pow-based IPs. The pow-based IPs decrease more by 1.97% than non-pow-based IPs. The results are consistent with the hypothesis that pow-based IPs have more severe environmental impacts. We use $return_{it}$ and $supplyChange_{it}$ as additional dependent variables and the results with $return_{it}$ are consistent with the TMVGRs, indicating the changes of TMVGRs are mainly driven by the changes of token price.

6 Conclusion

The governance of IT infrastructure, including blockchain infrastructure, has emerged as a topic of importance. One aspect of such governance is assessing its impact on environmental sustainability. Despite its importance, this topic is rarely explored in the IS literature. The current study finds the increased awareness of Bitcoin mining's negative impacts spills

Table 6: Heterogeneous Effects of Web Page Environmental Disclosure

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dep. Variable	$TMVGR_{it}$	$return_{it}$	$supplyChange_{it}$	$TMVGR_{it}$	$return_{it}$	$supplyChange_{it}$	$TMVGR_{it}$	$return_{it}$	$supplyChange_{it}$
No. Observations	57,940	57,940	57,940	39,430	39,430	39,430	39,430	39,430	39,430
Cov. Est.	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered	Clustered
R-squared	0.0046	0.0132	0.0336	0.0039	0.0168	0.0416	0.0039	0.0168	0.0416
R-Squared (Within)	0.0032	0.0068	0.0214	0.0028	0.0106	0.0307	0.0028	0.0106	0.0307
Intercept	0.0568***	0.0510***	0.0058	0.0507***	0.0482***	0.0026	0.0509***	0.0485***	0.0024
	(0.0074)	(0.0071)	(0.0036)	(0.0079)	(0.0066)	(0.0040)	(0.0079)	(0.0067)	(0.0040)
$post_{it}$:$environment_i$	0.0037**	0.0028**	0.0009*						
	(0.0018)	(0.0014)	(0.0005)						
$post_{it}$:$registered_i$				-5.455e-05	1.383e-05	-6.838e-05			
				(0.0025)	(0.0023)	(0.0006)			
$post_{it}$:$address_i$							0.0014	0.0023	-0.0009*
							(0.0023)	(0.0022)	(0.0005)
$post_{it}$	-0.0020	-0.0015	-0.0006	0.0025*	0.0021*	0.0004	0.0018	0.0010	0.0008*
	(0.0015)	(0.0012)	(0.0004)	(0.0015)	(0.0013)	(0.0004)	(0.0013)	(0.0010)	(0.0004)
$environment_i$	-0.0004	-0.0004*	2.274e-05						
	(0.0002)	(0.0002)	(7.756e-05)						
$\log(mCap_{i,t-1})$	-0.0079***	-0.0072***	-0.0007	-0.0073***	-0.0070***	-0.0003	-0.0073***	-0.0070***	-0.0003
	(0.0010)	(0.0010)	(0.0005)	(0.0011)	(0.0009)	(0.0006)	(0.0011)	(0.0009)	(0.0006)
$weekReturn_{i,t-1}$	-0.0008	0.0320**	-0.0329**	0.0010	0.0369***	-0.0359**	0.0010	0.0369***	-0.0359**
	(0.0033)	(0.0140)	(0.0158)	(0.0052)	(0.0122)	(0.0162)	(0.0052)	(0.0122)	(0.0162)
$monthReturn_{i,t-1}$	0.0029***	0.0015	0.0014**	0.0029***	0.0013	0.0015**	0.0029***	0.0013	0.0015**
	(0.0007)	(0.0009)	(0.0006)	(0.0005)	(0.0011)	(0.0007)	(0.0005)	(0.0011)	(0.0007)
$3MonthReturn_{i,t-1}$	0.0005*	-0.0002	0.0006***	0.0003	-0.0003	0.0006***	0.0003	-0.0003	0.0006***
	(0.0003)	(0.0003)	(0.0002)	(0.0004)	(0.0003)	(0.0002)	(0.0004)	(0.0003)	(0.0002)
Entity FE	○	○	○	○	○	○	○	○	○
Time FE	○	○	○	○	○	○	○	○	○

Notes: Entries in parentheses below the coefficient estimates are standard errors. The 'Entity' and 'Time' effects incorporated in each model account for the platform-specific and the year-by-month-by-day fixed effects respectively. 'Clustered' standard errors are calculated based on grouping at the platform level. Levels of significance for the coefficients are denoted by asterisks, with *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

over to other token-based platforms and moderates the green effects, which advances our understanding of these platforms' responses to the public awareness of environmental issues. As blockchain represents an emergent form of IT data infrastructure, our findings show the heterogeneity of token-based platforms by dividing them into IPs and APs and their disparate degrees of environmental hazard. The layered structure between infrastructure platforms and application platforms reveals the complex interplay between IT governance and environmental responsibility.

Our research underscores the role of awareness in IT infrastructure governance practices for policymakers and platforms. As awareness could be shaped by non-regulatory means, policymakers should emphasize education campaigns to promote environmentally conscious practices and awareness of their long-term benefits, especially in such a global and unregulated Web 3.0 market. Besides, policymakers should ensure the reliability of disclosed environmental information by discouraging deceptive 'greenwashing' and promoting genuine sustainability efforts. Furthermore, platforms should consider the timing of their disclosure. Disclosing environmental information during periods of low awareness may backfile, even if eco-friendly practices are genuine. Lastly, we also provide implications to token holders, especially short-term token investors, who should consider awareness spillover in their investment strategies.

Our research has certain limitations. Firstly, we focus on platforms with a token market value of over US$100 million, which may not fully capture the full market, even though such platforms are the most influential with higher data quality. Secondly, awareness is a complex construct and difficult to measure accurately without surveys. We use a dummy variable to measure the relative change. Thirdly, we focus on the web page environmental impact disclosure. Although web pages serve as the primary information source for platforms, considering alternative channels that target specific subgroups of token holders could be more comprehensive. Fourthly, considering IPs' self-reported data are not verified, the current research does not investigate their heterogeneous energy consumption. Lastly, we estimate only the net effect rather than the individual green-costing and green-enhancing effects. Future studies should investigate the mechanism that produces the green-costing and green-enhancing effects observed in the current study.

Appendix A: Variable Definitions

Variable	Definition
$TMVGR_{it}$	Daily percentage change in the platform's market capitalization (size).
$return_{it}$	Daily percentage change in the platform's token price.
$supplyChange_{it}$	Daily percentage change in the platform's token supply.
IP_i	Indicator variable that equals one for token-based platforms are IPs and zero for APs.
$postShock_t$	Indicator variable that equals zero if the date is before May 12, 2021, and one otherwise.
$post_{it}$	Indicator variable that equals to one if the date is after web page environmental disclosure, and zero otherwise. The variable varies across time and units.
$environment_i$	Indicator variable that equals one if the web page disclosure is environmental information, and zero if the web page disclosure is social information.
$preShock_t$	Indicator variable that equals one if the date is before May 12, 2021, and zero otherwise.
$log(mCap_{i,t-1})$	The natural logarithm of market capitalization one day prior.
$weekReturn_{t-1}$	Percentage change in the token price during the previous week one day prior.
$monthReturn_{t-1}$	Percentage change in the token price during the previous month one day prior.
$threeMonthReturn_{t-1}$	Percentage change in the token price during the previous three months one day prior.
$registration_i$	Indicator variable that equals to one if a token-based platform is officially recognized as a legal entity in a particular country, and zero otherwise.
$address_i$	Indicator variable that equals to one if a token-based platform is officially registered with a full address for its organization, and zero otherwise.
pow_i	Indicator variable that equals one if the IP uses proof-of-work consensus, and zero otherwise.

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