Status Regain and Validator Performance: Evidence from Blockchain Platform

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Abstract

The paper examines the effects of providing validators with status on transaction verification performance in blockchains (e.g., Delegated Proof-of-Stake). In particular, the paper focuses on how status regain (i.e., validators having lost status but regaining it) affects their performance and whether the effect of status regain diminishes over time. It is argued that losing status may induce behavioral changes once they regain status. However, it is not clear how losing and regaining status might affect, positively or negatively, validators' performance in transaction verification. The results indicate that status regain positively impacts their performance in transaction verifications. Further, we find that the length of status loss negatively moderates the impact of status regain on performance. Also, we find that the status position before status loss positively moderates the impact of status regain on performance. Implications of the results for practice and research are discussed.

Keywords: Blockchain security; status as reward; Delegated Proof-of-Stake blockchains

Introduction

Blockchains allow network security without a central governance structure (Casey and Vigna 2018). In blockchains, a group of special users with technical skills, known as validators, play a critical role in network security (Easley et al. 2019). Validators verify blockchain transactions and protect transaction validity from malicious attacks (Catalini and Gans 2020). As of 2017, more than 300 million blockchain transactions are being verified and generated daily (Morris 2017). However, it is not always easy to motivate validators to complete transaction verifications (Carlsten et al. 2016). As such, one of the important challenges for blockchain security has been to motivate actors to participate in transaction validation (Rossi et al. 2019).

To address this issue, blockchain technologies have employed different rewards to motivate validators to complete transaction verifications. Certain blockchain technologies (e.g., Bitcoin Core, Ethereum, and Cardano) provide economic incentives for validators. The most notable examples are the Proof-of-Work (PoW) and Proof-of-Stake (PoS) blockchains. However, there is a growing concern about the inconvenience of the economic incentives, notably known as the "transaction fee crisis" (Huo 2017; Lee 2018). For instance, Ilk et al. (2021) found that over 286 million US dollars had been paid as monetary rewards for the miners in Bitcoin Core in 2018.

Due to the expensive fees involved with this approach, an alternative reward mechanism based on status recognition has been developed and implemented, e.g., Steem, Tron, and EOS.IO (Bamakan et al. 2020). The most notable example is the Delegated Proof-of-Stake (DPoS) blockchains. The validator status can be described as an explicit position concerning social resources and represents a group of individuals selected to contribute to network security. Hence, the validator status is a social reward as status can represent peer approval, social recognition, and trustworthiness (Bhanji and Delgado 2014; Jensen and Roy 2008; Jiang et al. 2013; Lount Jr and Pettit 2012). Furthermore, the validator status can be a means to obtain future economic benefits as it enables validators to win block rewards (i.e., a fixed amount of cryptocurrency reward for each block of complete transaction verification).

Status provides valuable resources (Anderson et al. 2015), but our understanding of how and why status can motivate individuals in blockchains is still unknown. The evidence suggests that status may not always motivate individuals to generate performance (Bothner et al. 2012). Its motivation effect can diminish over time (Burt 2010; Pareto 1991; Walker and Smith 2002). Individuals can develop negligence after status gain and may miss their task. This is a critical issue in blockchains, as negligence by a validator can threaten network security.

One important phenomenon associated with status is that validator status is transient and can be gained, lost, and regained over time. That is validators often temporarily lose status and regain it later. Considering the limited number of special users with technical equipment and skills required to perform validator tasks (HashrateIndex 2023; Wilson 2022), losing status may not just exclude such validators but may need to induce behavioral changes once they regain status. It is not clear how losing and regaining status might affect, positively or negatively, validators' performance in transaction verification. Prior research has focused mainly on economic reward and their effects on validators' transaction verifications in blockchains (Easley et al. 2019; Ilk et al. 2021; Mueller 2020).

Research is needed to examine the effect of status on validator performance because the knowledge about the impact of economic reward in PoW or PoS blockchains does not necessarily apply to status regain in DPoS blockchains. First, the experiences that status regain can likely differ from those that gaining economic reward again can provide. This can result in underlying psychological effects of status regain being different from those of the economic reward (Spreckelmeyer et al. 2009). Furthermore, its value functions (Huberman et al. 2004; Loch et al. 2000) and effect patterns (Ball and Eckel 1998; Besley and Ghatak 2008; Bhattacharya and Dugar 2012) can differ from those of economic reward. This paper examines the effect of status on validator performance, particularly whether regaining status affects validator performance.

Our research question is:

RQ*: How does status regain affect the validators' transaction verification performance?*

To address this question, we draw on reinforcement theory (e.g., Killeen and Fetterman 1988), which argues that the experience of losing a benefit can increase reward sensitivity and stimulate desired behaviors (Killeen and Fetterman 1988; Skinner 1965). The theory suggests that removing a reward can allow an individual to learn the relationship between wrongful behaviors and the consequences (Skinner 1965). Hence, they are less likely to repeat the behavior that produced the removal of benefit and more likely to repeat the behaviors that produced the reward. Furthermore, the theory posits that the significance of a reward can diminish over time following their presentation (Ferster and Skinner 1957). Reinstatement of the reward (Campbell and Jaynes 1966; Skinner 1969) can cause arousal and increase the significance of reward as a reinforcer for desired behavior (Killeen and Fetterman 1988). Hence, we hypothesize that validators who have experienced status regain will generate fewer incomplete transaction verifications.

To empirically examine our hypotheses, we use status regain as our treatment and analyze the effect of treatment on transaction verification performance in blockchain technology. We used data from Steem and a natural experiment in which we used status regain as a treatment and compared the number of incomplete transaction verifications by validators who have experienced status regain to validators who have not experienced status regain. We apply a difference-in-differences with a two-way fixed effects approach to compare transaction verification performance between the treatment and control groups. Our results show that status regain has a positive effect on validator performance.

Our study contributes to IS literature by adding extant knowledge about blockchain security. The study identifies a significant impact of status regain on validators' transaction verification performance and answers the question, "What motivates validators to participate in transaction validation?" (Rossi et al. 2019). Our study also has significant practical implications. Our findings can be useful for designing blockchain technologies for blockchain security. Practitioners can better design a status system that can enhance blockchain security.

The rest of this paper is organized as follows: In the background section below, we briefly present some fundamental concepts of validator status in blockchains. Next, we summarize research on blockchain security, especially the one focusing on validators' transaction verifications. In the following section, we present a theoretical background and hypothesis development. We discuss reinforcement theory and present a behavioral mechanism that underlies the relationship between status regain and transaction verification performance. We then describe the research context, the data used in our analysis, and the results. We conclude the paper by discussing the contributions and implications of our study.

Background: Status as a reward mechanism in blockchains

Validator status is used to motivate the complete transaction verifications. The validator status is delegated from a network of users to verify transactions on users' behalf (Eigelshoven et al. 2020). Status gives decision rights over the authentication of transactions and the validity of cryptocurrency (Swan 2015). However, the validator status is given along with its role to perform transaction verifications (Saad and Radzi 2020). Hence, complete transaction verification by a validator can be seen as accomplishing the validator role by a network of users. This can give a reason for the users to evaluate the validator as accountable and again endow the validator status to the validator in the following rounds. Validators are selected to perform the necessary security work for the blockchains on behalf of users. Their status provides higher levels of social resources such as peer approval, reputation, and economic benefits.

However, research in other contexts indicates that individuals with status often develop complacency (Burt 2010; Pareto 1991; Walker and Smith 2002) and often perform non-productive behaviors (Weber 1978). Status can be an end in itself (Goode 2020; Weber 1978). Therefore, it can no longer be a significant motivator for behaviors. Hence, in the context of blockchain, motivating validators with status can lead to incomplete transaction verifications, which can threaten network security.

Blockchain technologies can provide status loss for incomplete transaction verifications. Incomplete transaction verifications by a validator can be considered an unsuccessful accomplishment of the validator role by a network of users. So, this can give a reason for users to demote the validator and take away the validator status in the following round of validator selection.

Prior Research

Research on the governance of blockchains has acknowledged the importance of rewards for the validators' transaction verifications and network security in blockchains (Andersen and Bogusz 2019; Beck et al. 2018; Pelt et al. 2021; Rossi et al. 2019; Zachariadis et al. 2019; Ziolkowski et al. 2018; Ziolkowski et al. 2020). Although a few studies have examined the effects of rewards on validators' transaction verifications, they have focused solely on economic rewards in blockchain technologies and their impacts on validators' transaction verifications (Easley et al. 2019; Ilk et al. 2021; Mueller 2020).

Prior studies on the impact of reward on validators' transaction verifications have focused on economic reward. They have examined the impacts of economic reward (e.g., the block reward or transaction fee) and cost (e.g., computing power or staking power) on the transaction verifications in the blockchains. Also, they have investigated the impacts of the algorithmic designs (e.g., reward size and difficulty level) or the market (e.g., exchange price and volatility) on the transaction verifications as contingent conditions for the monetary reward and opportunity cost.

Notably, Ilk et al. (2021) found that higher average monetary rewards (i.e., transaction fees) lead to an increase in the miners' average amount of block generation but shorter median transaction verification time in Bitcoin Core. Furthermore, it also found that higher hardware costs for miners lead to a decrease in the miners' average amount of block generation. Easley et al. (2019) found that the miners are sensitive to the monetary reward in Bitcoin Core and perform more transaction verifications with the monetary reward than without the monetary reward on average. Mueller (2020) found that miners in Bitcoin Core have an asymmetric response to Bitcoin price shocks. It found that the miners continue performing the high difficulty rate of mining (increase the difficulty rate) when the Bitcoin price increases and decreases. However, the study found that the Ethereum validators have a symmetric response to price shocks. The validators in Ethereum reduce their participation in the difficulty rate of validation (reduce the difficulty rate) when the Ethereum price decreases.

While some studies have investigated the impact of economic reward on the transaction verifications in the blockchains (Easley et al. 2019; Ilk et al. 2021; Mueller 2020), no prior research has explicitly investigated whether and how the regain of validator status would impact the validators' transaction verifications in the blockchains. This gap in the literature is important because the extensive knowledge of the implications of the economic reward does not necessarily apply to the status regain in the blockchains.

First, one important aspect of status is that it can be transient, and its benefits can be gained, lost, and regained. Unlike economic rewards that cannot be taken away once received in blockchains, validator status can be lost and regained. Status regain can provide experiences of losing all benefits once an individual has and then regaining them (Pettit et al. 2010). However, gaining economic rewards cannot provide experiences of losing benefits. Hence, experiences that status regain can provide likely differ from those that gaining economic reward can provide. These different experiences can result in underlying psychological effects of status regain likely to differ from those of continuously gaining economic reward (Spreckelmeyer et al. 2009). Also, the value functions of status as reward can likely be different from those of economic reward (Huberman et al. 2004; Loch et al. 2000). Status as a relative positional good allows competition among individuals and encourages the individuals to work harder with a zero or small marginal cost (Besley and Ghatak 2008). Therefore, its effect patterns can likely differ from those of economic reward (Ball and Eckel 1998; Besley and Ghatak 2008; Bhattacharya and Dugar 2012). As a result, current knowledge from studies on the economic reward in the blockchains cannot explain how status regain impacts the validator performance because the economic reward does not provide the loss experience that status dynamics can provide. Also, current knowledge from studies on the economic reward in the blockchains, which mainly focus on how to develop algorithmic designs to moderate the impacts of the economic rewards on the performance, cannot be directly applied to status regain in the blockchains because it has different contingent conditions by which it becomes significant. From these, there is a missing knowledge about the impacts of status regain and the contingent conditions by which it becomes more effective on validators' transaction verification performance in the blockchains. This requires a new development of theoretical arguments and investigation.

Theoretical Background and Hypotheses Development

Reinforcement theory

We draw on reinforcement theory (Ferster and Skinner 1957; Skinner 1938; Skinner 1950; Skinner 1965; Skinner 1969), which provides theoretical explanations about how and why rewards and the experience of losing rewards can affect behaviors. Reinforcement theory considers an individual's behavior as a function of consequences (Ferster and Skinner 1957; Skinner 1938). The theory posits that individuals learn behaviors based on consequences (Skinner 1950). It argues that individuals are more likely to repeat behaviors that result in positive consequences in their experiences (Herrnstein 1970). Here, rewards can provide positive consequences for individuals and, thereafter, can motivate them to repeat the desired behaviors (Skinner 1938). When rewards are given to individuals, they would learn the behaviors that rewarded them (Griggs 2010).

However, reinforcement theory suggests that the significance of the reward can diminish over time (Bahrick et al. 1952; Killeen and Fetterman 1988). On the contrary, removing a reward can cause arousal and increase reward sensitivity, significantly motivating the desired behavior (Yechiam and Hochman 2013). Furthermore, this can provide a new opportunity for the individual to learn about desired behaviors based on the negative consequences (Skinner 1965). From this learning, they are less likely to repeat the behavior that resulted in removing the benefit but more likely to repeat the behaviors that produced the benefit.

Status regain has status loss before and after status gain. From the theory perspective, the experience of the negative consequences when they lose a reward can break the diminishing sensitivity of the reward and reactivate the reward's significance (Killeen and Fetterman 1988). Based on this, we consider that the experience of losing status can motivate the validators to contribute better to their task performance. Furthermore, we consider that the experience of losing the benefits from status can provide an opportunity to learn the association between their past wrongful behaviors and the loss. From this learning, we consider that the validators who have experienced the status loss will be less likely to repeat the past behaviors that they considered to result in a status loss but more likely to repeat the behaviors that they consider contributing to status gain. Since validators who regained status may generate fewer incomplete transaction verifications than validators who have no experience of losing the status, in this theoretical viewpoint, we propose that status regain can motivate the validators to perform better in transaction verifications and hypothesize as follows.

Hypothesis 1: *Validators who have experienced status regain will perform better in transaction verifications (measured by a smaller number of incomplete transaction verifications) after status regain than validators who have not experienced status loss.*

However, the significance of loss experience can be diminished over time as individuals' memory and arousal decay (Killeen 1975). Reinforcement theory highlights the importance of time elapsed since the punishment regarding arousal decay (Ferster and Skinner 1957). The theory considers that high states of arousal are required for reward or punishment to be significant enough to facilitate learning and direct desired behaviors. However, arousal levels can decay exponentially over time with high availability of other external factors confounding (Killeen et al. 1978). The theory considers that there is a negative moderating effect of the schedule of punishment on the effect of punishment on desired behaviors (Kerns 1975). From these, we consider that the significance of loss experience in status regain can also diminish over time as individuals' memory and arousal decay. Here, we focus on the length of status loss before status regain. Status loss experience can be significant enough to cause arousal at its emergence. However, it may show reduced memory and arousal as time after status loss and time until status regain increases. In this theoretical viewpoint, we propose that the effect of status regain can be negatively moderated by the length of status loss before status regain and hypothesize as follows.

Hypothesis 2a: *The effect of status regain on transaction verification performance is negatively moderated by the length of status loss before status regain. i.e., the positive effect of status regain on transaction verification performance decreases as a validator has a longer status loss (measured by the number of weeks when a validator has no status after the first status loss week).*

In addition, the significance of loss experience can be dependent on the magnitude of loss. Reinforcement theory considers that there is a positive moderating effect of size or amount of punishment (Volkert et al. 2005). From this, we consider that a validator who had a relative standing regarding the security of validator status may experience status loss as more painful than a validator with a lower relative standing. In this theoretical viewpoint, we propose that the effect of status regain can be positively moderated by status position before the status loss and hypothesize as follows.

Hypothesis 2b: *The effect of status regain on transaction verification performance is positively moderated by the status position before the status loss. i.e., the positive effect of status regain on transaction verification performance increases as a validator had a higher status position (measured by the number of times a validator won status in a week) before status loss.*

Empirical Analyses

Research Setting

To estimate the effect of status regain on transaction verification performance, we use data from a DPoS blockchain technology, Steem. Steem has created a new block every 3 seconds with more than 0.15 million daily transactions. Steem denotes, "A witness (validator) is responsible for signing and validating blocks for the Steem blockchain" (Steem 2017). Validators play a critical role in the network security of the blockchains (Easley et al. 2019). The consensus mechanisms in other leading DPoS blockchain technologies (e.g., Tron, Hive, and EOS.IO) and those in nascent blockchains also use status change to motivate complete transaction verifications. Validator status can be a means to obtain future economic benefits as it enables validators to win block rewards. Validators can earn a fixed amount of cryptocurrency reward for each block of complete transaction verification.

In Steem, users can vote for thirty candidates at any time. Once a user votes, this voting decision is held until the user changes the decision. Every 63 seconds, a new list of 21 validators with the maximum votes weighted by user stakes is announced. Hence, validator status can be lost or regained at any round. However, it can be difficult for validators to be aware of a minute-level status change. Also, validators' varying individual levels of active use may obstruct the treatment exposure. Hence, we focus on status change on a weekly level. Steem describes the validator as "a position for the people who are chosen by the community to support platform and run consensus protocol to ensure security and validity of transactions on the blockchain" (Steem 2017). The validator is expected to complete the verification of each block. However, some may miss the verification and generate incomplete validation. Incomplete verification makes the network vulnerable before the next available validator verifies the block in the next time slot.

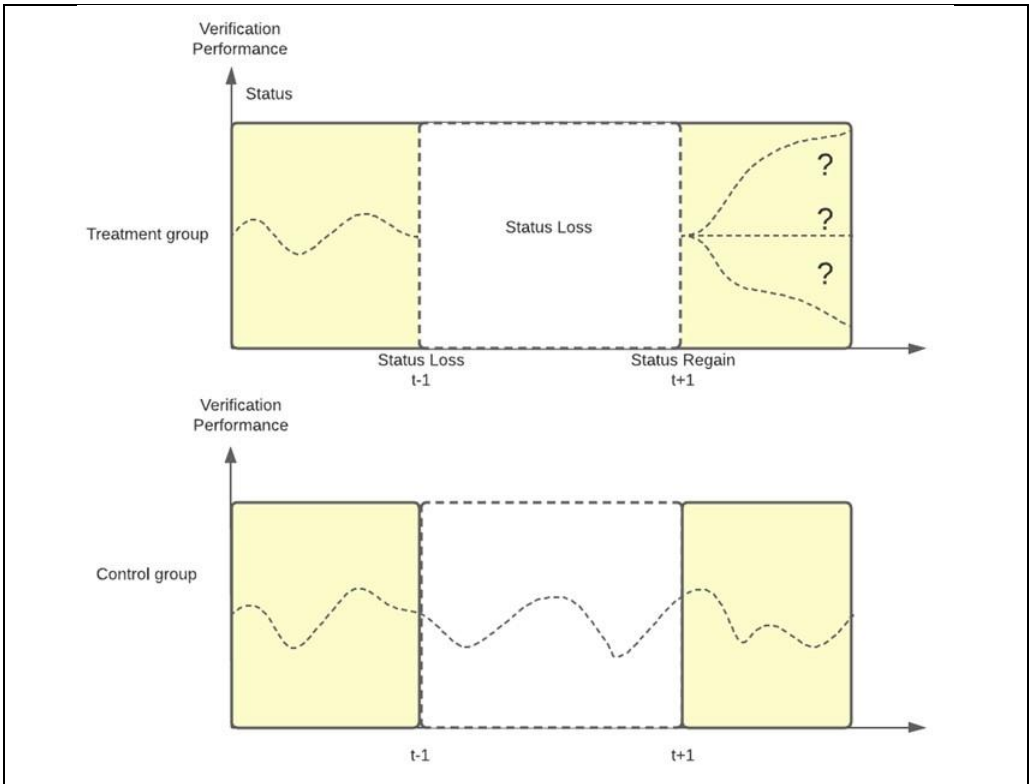

Figure 1. Conceptual Illustration of Empirical Setting

It is important to note that transaction verification is unavailable for individuals when their status is lost but available when their status is regained after status loss. As noted, a validator status is required to perform the transaction verification. This provides a research setting with the transaction verification performances only when individuals have validator status (either when maintained or regained status).

There can be different levels of effort when verifying transactions, which could be correlated with their future transaction verification performance. To ensure that the selection effect will not be confounded with our estimation of the status regain effect, we adopt an identification strategy that compares transaction verification performance before and after the status loss and between the treatment and control groups. Specifically, we only include the periods (Colored quadrants in Figure 1) and compare the transaction verification performance before and after the status loss and between the treatment and control groups.

Data

Our data is mainly from Steem. We obtained validator data from April 13, 2016, to August 12, 2016. However, users have shown different levels of daily active use. On average, they have demonstrated 3.46 days of inactivity (i.e., no user activity) on Steemit. It is evident that users may not use the technology daily and that they may not be aware of the daily status change. Furthermore, the varying levels of daily inactivity between users can result in different timing of treatment exposure across users. As such, daily level observation may provide bias in measurements as there can be a disparity between the day of a user's status loss and the day the user logged in to the technology and experienced status loss. The daily level of user inactivity can obstruct the users from being aware of daily level status changes, and it can hinder accurate estimation of the effect of the loss experience. To mitigate these two issues, we aggregated the data into weekly data. We considered the weekly level of active use on average and assumed that users could be aware of status changes every week.

In this study, we construct the data at the validator level (i.e., each observation corresponds to a validator). We create an observation each time a validator first gains the status in our dataset. The first period corresponds to the week a user first gained the status ($t = 0$). We observe each validator from the first to the sixth period when a validator maintained or regained the status a sixth time.

For the control and treatment group, we only include individual validators who have maintained the status (control group) and have ever experienced the status regain (treatment group) in our sample. This inclusion excludes many validators as most either had a status for one week or lost status but never regained it. The dataset contains 159 validators in the control group and 114 validators in the treatment group and their transaction verification performances. Also, it includes individual information such as reputation score, the amount of cryptocurrency tokens an individual owns, tenure, and other individual activities such as the number of postings and comments, which might affect how a validator regained the status.

Variables and Measures

To examine the effect of status regain on transaction verification performance, we first identified each validator's status based on whether and when they lost and regained status. Given the rolling rounds of status endowment and demotion in the blockchain, we define our treatment $Treatment_{it}$ as whether validator i regained the status in week t or not. In our analysis, validators who have regained the status constitute the treatment group, while those who have maintained the status represent the control group.

We generated a dependent variable that represents the extent of each validator's transaction verification performance. $Missing_{it}$ indicates how many blocks of incomplete transaction verification validator i generated on the blockchains in week t.

Variables	Description
Missing Transactions	The number of incomplete block transaction verifications by validator i in week t
Treatment	Whether validator i regained status in week t
MVest	The amount of cryptocurrency tokens a validator i owned in week t in a million unit
Reputation Score	The level of reputation scores a validator i had in week t
Post and Comment	The total number of posts and comments by validator i in week t
Tenure	The number of weeks validator i has been on the blockchain technology until week t

Table 1. Variable Description

In addition, we defined five variables that may affect the dependent variable. They are MVest, Reputation Score, Post and Comment, and Tenure. Specifically, $MVest_{it}$ indicates the number of cryptocurrency tokens

(Vest) a validator i owned in week t. The unit is in the millions. Like Bitcointalk.org for Bitcoin Core (Xie et al. 2020), Steem has an online forum called Steemit, built on top of Steem. $Reputation_{it}$ indicates the level of reputation scores a validator i had in week t. Steemit displays and algorithmically calculates the value a user has brought based on the user's up-voted and down-voted posts and comments (Steem 2019). Discussions between users in Steemit can potentially affect validators' behaviors (Fernández Vilas et al. 2021; Hsieh et al. 2017; Vasek et al. 2014). $Post\_and\_Comment_{it}$ indicates the total number of posts and comments by a validator i in week t on Steemit. Lastly, $Tenure_{it}$ indicates the number of weeks a validator i has spent on the blockchain until week t. This may capture the duration and experience a validator learned about the culture and norms within the system. All variables except tenure are log-transformed for the normality using log $(X + 1)$. Table 2 shows descriptive statistics for the sample. On average, an individual validator missed 30.463 blocks of transaction verifications in a week.

Variables	Mean	SD	Min	Max
Missing Transactions	0.535	1.565	0	7.372
MVest	0.241	0.886	0	5.399
Reputation Score	3.340	0.308	0.693	4.309
Post and Comment	0.167	0.610	0	4.644
Tenure	3.159	2.263	0	15
Note. All variables except tenure are log-transformed. Tenure is measured by the number of weeks.				

Table 2. Summary Statistics

Analyses

We conduct our primary analyses using propensity score matching (PSM) with a panel difference-in-differences (DID) estimation (Acemoglu et al. 2019; Yu et al. 2022). These techniques have been commonly used to analyze the causal effect in quasi-experiment research design (Deng et al. 2022; Pamuru et al. 2021; Qiao and Rui 2022; Yu et al. 2022). Specifically, this technique enables us to estimate the treatment effect by capturing the differences in transaction verification performance between the treatment and control groups before and after they regained the status to that of the control group.

Propensity Score Matching

A key challenge in quasi-experimental settings is that treatment assignments may not be random. In our context, individual characteristics and activities might affect how a validator regains the status. To address the endogeneity concerns, we use propensity score matching to construct a balanced sample with a comparable control group of validators who have maintained their status and a treatment group of validators who have regained their status. We include the four variables that may affect the dependent variable. They are MVest, Reputation, Post_and_Comment, and Tenure. More specifically, we match with all values of variables at week 0 ($t = 0$), which is a week before any status regain (pre-treatment). We estimate the propensity score using a logit function and use the nearest neighbor matching without replacement to obtain our final matched sample.

Variables	Control Group (Maintained Status)	Treatment Group (Regained Status)	K-S p-value
MVest	0.08 (0.46)	0.25 (0.75)	0.982
Reputation Score	3.28 (0.14)	3.27 (0.09)	0.999
Post and Comment	0.04 (0.14)	0.02 (0.11)	0.999
Tenure	0.04 (0.30)	0.16 (0.26)	0.277
Note. All variables except tenure are log-transformed. Tenure is measured by the number of weeks.			

Table 3. Covariate Balance between Treated and Control Groups

Next, we validate our matching by testing the balance between the variables of the treatment group against those of the matched control group. We conducted a Kolmogorov-Smirnov test (Deng et al. 2022), and we concluded that the distributions of all variables were not significantly different between the control and treatment groups after matching (p-value >0.1). As in Table 3., the distributions are virtually identical, with the Kolmogorov–Smirnov test for equality of distributions being insignificant. This matching gave us a matched control group comparable to the treatment group of 114 validators.

Difference-in-Differences Analyses

We applied a difference-in-differences (DID) with a two-way fixed effects approach as our identification strategy (Acemoglu et al. 2019; Yu et al. 2022). This approach enables us to estimate the treatment effect by capturing the differences in transaction verification performance between the treatment and control groups before and after they regained the status to that of the control group. Since validators can lose status and re-gain status across time (which rarely happens in our matched sample), we incorporated $Treatment_{it}$, which measures whether validator i regained the status in week t into the model. It takes the value of one for the validators from the treatment group after the treatment starts and zero otherwise. Hence, this equals the interaction of $Treatment \times After$ term in the standard difference-in-differences (Acemoglu et al. 2019; Greenwood and Wattal 2017).

$$Missing_{it} = \beta_0 + \beta_1 Treatment_{it} + \beta X_{it} + \delta_i + \tau_t + \sigma_{it}, \quad (1)$$

where i denotes each individual and t for each week. δ_i are the individual fixed effects that account for the time-invariant individual-specific unobservable characteristics. τ_t are week fixed effects that control for the unobserved temporal effects. σ_{it} captures the idiosyncratic random errors. β_1 is the coefficient we are interested in since it captures the impact of status regain on the number of incomplete transaction verifications. X_{it} denotes the control variables and includes $MVest_{it}$, $Reputation_{it}$, $Post\_and\_Comment_{it}$, and $Tenure_{it}$. We estimated robust standard error clustered at the individual level for the equation to mitigate potential heteroscedasticity concerns (Goldfarb et al. 2022).

Furthermore, we are also interested in investigating how the temporal and magnitude dimensions of status loss moderate the effect of status regain on performance. We investigate whether the length of status loss ($NoStatusWeeks$) and status position before the status loss ($StatusPosition$) respectively moderate the effect of status regain. Here, $NoStatusWeeks$ measures the number of weeks when a validator has no status after the first status loss week. $StatusPosition$ measures the number of times a validator received the status in a week before the status loss. We test hypotheses 2a and 2b. For this, we include these variables in our difference-in-differences specifications as interactions with the treatment variable.

Results and Discussion

We present our results in Table 4. For Hypothesis 1, we assume that validators who have experienced status regain will perform better in the transaction verification performance. This is supported in our result (column 1). The coefficient is negative and statistically significant ($p<0.01$) for the number of incomplete transaction verifications. The result shows that validators who have experienced the status regain generate fewer incomplete transaction verifications after the status regain and show significant improvements in their transaction verification performance.

Variables	log(Missing Transactions)		
	(1)	(2a)	(2b)
Treatment	-2.390*** (0.326)	-3.541*** (0.562)	-1.118*** (0.220)
Treatment × NoStatusWeeks		1.637*** (0.492)	
Treatment × StatusPosition			-20.515*** (1.571)
MVest	-0.608* (0.350)	-0.597* (0.345)	-0.697** (0.336)
Reputation Score	-0.969* (0.504)	-0.974** (0.487)	-0.726 (0.523)
Post_and_Comment	-0.359** (0.082)	-0.347** (0.148)	-0.364** (0.151)
Tenure	0.028 (0.152)	-0.181 (0.112)	0.006 (0.080)
Individual and Time FEs	Yes		
Observations	1,368		
R-squared	0.027	0.025	0.011
Note. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All variables except tenure are log-transformed. Tenure is measured by the number of weeks.			

Table 4. Status Regain and Incomplete Transaction Verifications

In addition to the effect of status regain, we investigate the impact of temporal and magnitude moderators for the effect of status regain. For Hypothesis 2a, we assume that the positive effect of status regain on transaction verification performance is negatively moderated by the length of status loss before status regain. From the theoretical viewpoint, we consider that arousal and learning effects from the experience of losing status can diminish and be moderated over time. This is supported in our result (column 2a). The coefficient for the interaction term is positive and statistically significant ($p<0.01$). The result shows that the positive effect of status regain on the performance decreases as a validator had more weeks since the status loss.

For Hypothesis 2b, we assume that the positive effect of status regain on transaction verification performance is positively moderated by status position before the status loss. We consider that status loss from a higher-status position would provide a more painful experience than that from a lower-status position. From the theoretical viewpoint, we argue that a more painful experience of status loss would amplify the arousal and the learning in status regain. This is supported in our result (column 2b). The coefficient for the interaction term is negative and statistically significant ($p<0.01$). It shows that the positive effect of status regain on the performance increases as a validator had a higher status position before status loss.

Robustness Checks

We perform several additional analyses to ensure the robustness of our results. First, we test whether our sample's observations after matching fulfill the parallel trend assumption. For this, we use the Augmented Dickey-Fuller test of stationarity. This is commonly used in past studies (e.g., Khern-am-nuai et al. 2018; Pamuru et al. 2021) to test whether the sample's observations after matching fulfill the parallel trend assumption. The mean, variance, and auto-correlation structure in a stationarity time series do not change over time. The alternative hypothesis of the test is that variables are generated by a stationary method, while the null hypothesis would be the presence of a unit root in the data. The test for our dependent variable rejects the null hypothesis (Z(t)= -98.88, p<0.01), and it suggests that the parallel trend assumption holds.

Second, we check that the result of our analysis is not simply a consequence of spurious correlation. We conducted a placebo test to check if our results could be driven entirely by chance. We randomly assigned the treatment group and time and re-estimated our main analysis. We repeated this exercise 1,000 times. The random coefficients are expected to be insignificant because they should not exist in the considered data. As in Table 6., the results show that the placebo coefficient is insignificantly different from zero, suggesting that the main result should be attributed to the status regain.

Mean of Random β_1	-0.002229
Std. Deviation of Random β_1	0.1884925
Replications	1000
t-statistic	-0.37396
p-value	0.7085
Note. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.	

Table 5. Placebo Test

Third, we replicate the main analysis using a different matching method, Coarsened Exact Matching (CEM). The result was robust with the main result. We present our results in Table 6. The treatment effect of status regain is negative and statistically significant (p<0.01) for the number of incomplete transaction verifications.

Variables	log(Missing Transactions)
Treatment	-2.462*** (0.329)
MVest	-0.523 (0.378)
Reputation Score	-0.710 (0.527)
Post_and_Comment	-0.439** (0.193)
Tenure	0.256** (0.102)
Individual and Time FEs	Yes
Observations	1,092
R-squared	0.038
Note. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All variables except tenure are log-transformed. Tenure is measured by the number of weeks.	

Table 6. Result using CEM

Lastly, we replicate the main analysis using the Tobit, Poisson, and Negative binomial models as alternative identification models for our dependent variable since it is a count variable. The results were robust to the main result. We present our results in Table 7. The coefficients for the treatment were negative and statistically significant (p<0.01) for the number of incomplete transaction verifications (Column Tobit, Poisson, Negative Binomial).

Variables	Missing Transactions		
	Tobit	Poisson	Negative binomial
Treatment	-187.772*** (24.423)	-2.464*** (0.933)	-2.954*** (1.083)
MVest	-52.040* (30.256)	-0.259 (0.361)	0.009 (0.831)
Reputation Score	27.817*** (39.317)	1.714*** (0.436)	1.612** (0.949)
Post_and_Comment	-1.908 (9.419)	-0.085 (0.270)	-0.186 (0.486)
Tenure	22.318*** (7.760)	-0.905*** (0.724)	-1.206** (0.686)
Observations	Yes		
Individual and Time FEs	1,368		
Note. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All independent variables except Treatment and Tenure are log-transformed.			

Table 7. Count Data Models

Post-hoc analysis

Research on status in other contexts highlighted the importance of experience as more experienced individuals are likely to base behaviors on their own experience, thus being less sensitive to status change (Hoch and Deighton 1989; Valentini et al. 2011).

Variables	log(Missing Transactions)	
	(3a)	(3b)
Treatment	-2.302*** (0.314)	-2.726*** (0.348)
Treatment × Tenure	-0.029 (0.044)	
Treatment × ValidatorExperience		0.229*** (0.053)
ValidatorExperience		-0.574*** (0.035)
MVest	-0.611* (0.352)	-0.282 (0.243)
Reputation Score	-0.971* (0.506)	0.111 (0.242)
Post_and_Comment	-0.360** (0.149)	-0.072 (0.101)
Tenure	0.062 (0.167)	-0.053 (0.139)
Individual and Time FEs	Yes	
Observations	1,368	
R-squared	0.026	0.169
Note. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1. All variables except tenure are log-transformed. Tenure is measured by the number of weeks.		

Table 8. Status Regain and Incomplete Transaction Verifications (Post-Hoc)

The studies identified that individual experiences can negatively moderate the impacts of status change on their performance (Hoch and Deighton 1989; Tamaddoni et al. 2022; Valentini et al. 2011). To test whether this holds in our contexts, we distinguish two different experiences: user experience ($Tenure$) and validator experience ($ValidatorExperience$), and examine whether each respectively moderates the effect of status regain. More precisely, we examine two moderators: (1) the number of weeks an individual has spent as a user on the blockchain until the week ($Tenure$), and (2) the number of blockchain transactions a validator has made on the blockchain until the week ($ValidatorExperience$). Again, we include these variables in our difference-in-differences specification as interactions with the treatment variable. The result in columns 3a and 3b shows that status regain has a positive and significant effect on performance ($p<0.01$). However, the result in column 3a shows that the effect is not significantly moderated by user experience ($p>0.1$). In contrast, the result in column 3b shows that validator experience significantly moderates the effect ($p<0.01$). The validator experience is reported to decrease the number of incomplete transactions. However, it is reported that the positive effect of status regain on performance is negatively moderated by the validator experience. This result supports previous findings in other contexts. Also, it is in accordance with our theoretical arguments that there is a general impact of status change but that the impacts of status change can be negatively moderated when arousal from the status change may not be significant from other factors. The results show that validator experience may make the validators less sensitive to status regain as an external factor, which may give them a psychological response, thereafter, relying more strongly on their own experience (Dickinson and Dawson 1988). This can be further investigated in future studies.

Conclusion

Blockchain can potentially revolutionize how network security can be managed (Beck 2018). However, this technology is still under continuous development. The inconvenience of economic rewards has been identified and led to the development of a new reward system based on validator status. This new reward mechanism has been shown to provide higher economic efficiency and scalability (Mingxiao et al. 2017; Saad and Radzi 2020). However, the limited significance of status by nature, such that individuals with status often develop complacency (Burt 2010; Pareto 1991; Walker and Smith 2002) and negligence (Weber 1978), has prompted to question whether and how the validator status can motivate the validators to generate complete transaction verifications. This question is particularly important, given that validators missed a substantial number of blocks of transaction verifications.

One important aspect of status is that it can be transient and can be gained, lost, and regained. Status regain can provide experiences of losing all benefits once an individual had and then regaining them. Focusing on this, this study investigated whether status regains encourage validators to perform future transaction verifications in blockchain technology. Based on reinforcement theory, this study further demonstrated the underlying mechanism that status regain motivates the validators to contribute to transaction verification performance.

Our study has several implications. First, our study contributes to the discussions about the significance of status rewards for network security in blockchain technologies. From growing concern about the inconvenience of economic rewards (Huo 2017; Lee 2018), a group of blockchains (e.g., DPoS blockchains) with status as a reward has collected much attention. Some studies have identified that status reward mechanisms provide higher economic efficiency and scalability in blockchain technologies (Mingxiao et al. 2017; Saad and Radzi 2020). However, the question of whether status reward can be a new significant reward to motivate validators was unanswered, and there was concern whether the status reward mechanism can promote security in the blockchains. This study finds the significance of status regains in motivating the validators' better transaction verification performance. This finding implies that status can be another new type of reward or blockchain security. Also, our study finds contingent conditions where the effect can be moderated. These can provide extant implications for developers.

Second, our study contributes to the blockchain security literature by filling an important research gap. One of the important challenges for blockchain security has been understanding "What motivates actors to participate in transaction validation?" (Rossi et al. 2019). For this, studies on blockchain security have been developed to identify the effectiveness and limitations of reward mechanisms (Carlsten et al. 2016; Ilk et al. 2021; Vasek et al. 2014). Prior studies have explored the significance of economic reward in blockchains and their effects varying on market conditions (Easley et al. 2019; Ilk et al. 2021; Mueller 2020). However, literature has not studied status rewards in blockchains, and the limitations of status rewards were unknown. Our study identified that impacts of status regain can be negatively moderated by the length of status loss before status regain. Furthermore, our study extended the reinforcement theory and provided a theoretical explanation of why the allocation of validator status may need to be dynamic and dispersed. The results show that status regain may have a limited motivation effect until a certain time after losing status. This finding highlights the importance of status change and provides another reason why the distribution of decision rights in blockchains may need to be dispersed (Ziolkowski et al. 2020).

Lastly, our study contributes to the status literature by extending the knowledge. A stream of literature highlights the importance of status gain as a reward (Doyle and Lount Jr 2022; Driskell and Mullen 1990) and loss as a punishment (Deodhar et al. 2019; Pettit et al. 2010). Although status literature provides an extant understanding of the directions of status effects, it hardly considers the trajectory of status change and how it affects individual performance. More specifically, the literature does not examine how the experience of losing status would impact performance after status is regained. This is particularly important, considering that status can be gained, lost, and regained. Furthermore, status literature has paid less attention to the temporal and magnitude of status change and their moderating effects on task performance. For this, this study provides significant findings for the impacts of status regain and its heterogeneous effects contingent on temporal and magnitude moderators.

Although our study provides extant implications, this study has several limitations. The first limitation pertains to using user activity data. Because we rely on user activity data, measurements of individual users' psychological responses to status regain are unavailable. Future research may consider measuring them via survey and investigating the effect of status regain on different psychological responses. The second shortcoming is related to the true randomization of treatment. The status is given and demoted by a network of users rather than a true random assignment. This setting is general to blockchain technologies rewarding with status. Hence, randomization in this context is infeasible. We adopt several matching methods to ensure balance in our analysis, but this remains a limitation.

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