

Shifts in the Relationships between Gas Price and User Activity in Ethereum Following Ethereum Improvement Proposal 1559

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Abstract

Ethereum 2.0 introduced several significant upgrades, one being Ethereum Improvement Proposal 1559 (EIP-1559), which changed how gas price is determined. This study examines the relationship between gas price and user activity on the Ethereum protocol following EIP-1559 sampled every minute from December 1, 2023, 00:00:00 to December 15, 2023 23:59:59. This study shows a weak positive Pearson correlation between gas price and user activity with a bidirectional Granger causality between them. In other words, an increase in gas price does not decrease user activity, and vice versa. This contrasts with an earlier study before EIP-1559, which showed a moderate to strong negative Pearson correlation between gas price and user activity, as well as an only unidirectional Granger causality from gas price to user activity. The explanation asserted in that earlier study was that when gas prices were high, users waited to submit a transaction, possibly to avoid overpaying. The shift observed in this study, where increases in gas price no longer decrease user activity, shows that EIP-1559 appears to have enhanced user confidence in gas price calculations. This in turn influences their decision-making. Specifically, users are generally more assured in continuing their transactions under the new mechanism, as can be shown from the observation that the raising in gas prices does not cause user activity to decrease. On the other hand, the new observation of Granger causality in which increases in user activity slightly increases gas price is likely a result of the new gas price formula introduced by EIP-1559, which takes into account the network congestion and caps the extent of gas price adjustments. This formula introduces a predictable link between user activity dynamics and gas prices, thereby providing greater certainty for users.

Keywords

Ethereum, EIP-1559, Gas Price, User Activity, Blockchain

1. Introduction

Among existing blockchains, Ethereum has gained significant attention not only due to its widespread adoption but also due to its features and capabilities. Ethereum introduced self-executing contracts where the agreement can be upheld through the execution of code. Such contracts are known as smart contracts (Ethereum Foundation, 2024d). This has allowed for the development of technologies like decentralized applications and decentralized finance.

Ethereum is a blockchain with a computer, called the Ethereum Virtual Machine (EVM), embedded in it. The EVM allows for application development in a decentralized, permissionless and tamper-resistant manner. Every node in the Ethereum network keeps a copy of the state of the EVM. Additionally, any node on the Ethereum network can request for the EVM to perform computations. Whenever such a request is broadcast, it is verified, validated, then executed by other nodes on the network. This process causes a state change in the EVM, which is committed to the local state and then propagated throughout the entire network. The cumulative record of all transactions as well as the EVM's present state is stored on the blockchain. This collective agreement on the EVM's state enables an immutable transaction record, which reduces the need for a central trusted authority to promote trust and transactions between parties (Ethereum Foundation, 2024e).

As a mechanism to determine who gets to use the blockchain's computing power, users must pay for gas. Gas is the fee required to successfully execute transactions on the Ethereum blockchain network. Gas price is determined by (Ethereum Foundation, 2024c):

- the computational complexity of the execution of the transaction.
- the network-wide demand for computing power at the time.

Prior to Ethereum Improvement Proposal 1559 (EIP-1559), miners determined the minimum gas required to execute a transaction. Users must then bid a gas price to have their transactions to be included in the next block. This mechanism has caused unpredictable gas prices (Ethereum Foundation, 2024b).

Ethereum implemented EIP-1559 on August 5, 2021, which introduced a new mechanism where the minimum gas required to process and execute the transaction is set by the Ethereum protocol (Ethereum Foundation, 2024c). The Ethereum protocol automatically adjusts, with a cap, the minimum price to reflect network congestion. This mechanism allows for transparency, allowing users to get an accurate estimate of the gas price, which ultimately influences their total expenditure on the transactions. Users can add an optional tip to incentivize miners and improve the priority of their transactions in the network. This mechanism aims to promote price predictability. As a side note, after the consensus mechanism switched to proof-of-stake, miners are being referred to as validators.

A study by Pierro and Rocha (Pierro & Rocha, 2019)—which observed, among others, gas price and user activity—was conducted prior to EIP-1559. At

that time, the minimum gas price was unpredictable as it was determined independently by each miner. Their study analyzed gas price and user activity, which were represented by the number of pending transactions at an interval of 15 seconds between December 1, 2018, and December 15, 2018. Their study reported a unidirectional Granger causality from gas price to pending transaction. Their result of the Pearson correlation test was -0.6 , indicating a moderate to strong inverse correlation: as the gas price increases, the number of pending transactions decreases. The suggested explanation was that when the gas price is high, users wait to submit a transaction in hopes of a lower price later, thus decreasing the overall number of pending transactions during times of high gas price.

Currently, the price of Ether (ETH) in US\$ is 40 times higher than when the previous study (Pierro & Rocha, 2019) was conducted. As noted in this earlier study, users tend to avoid overpaying for gas: if immediate transaction approval is not necessary, they may wait for lower gas prices to save money. With the implementation of EIP-1559, which offers users better gas price estimates, it is important to revisit the study to understand how users are responding to these changes.

This paper re-examines the relationship between gas prices and user activity using historical data taken after the implementation of EIP-1559. Datapoints were collected over a period of 15 days between December 1, 2023, and December 15, 2023, with an interval of 1 minute.

Section 2 presents a comparison of how gas is determined pre- and post-implementation of EIP-1559. Section 3 presents the main research question of the paper. Section 4 presents the methodology used to gather and analyze the data from Ethereum data sources. Section 5 presents and discusses the results. Section 6 presents the conclusions of the research.

2. Gas Price in Ethereum

EIP-1559 introduced significant changes to how gas price is calculated on the Ethereum network, away from the previously miner-controlled mechanism to the new protocol-controlled approach (Ethereum Foundation, 2024b). The detailed comparison of the mechanisms before and after EIP-1559 is elaborated below.

Pre EIP-1559 (Legacy Gas Model)

In this model, the gas price was determined entirely by the market through a first-price auction model, with a minimum amount set by the miners. The user sends a transaction with a gas price bid, and miners choose the transaction that offers the highest bid. The transaction that gets included would pay the entire bid amount to the miner (Ethereum Foundation, 2024b).

This mechanism was identified to have disadvantages, which lead to inefficiencies such as gas price volatility, problems with high and unpredictable gas prices, as well as instability of the blockchain. EIP-1559 was introduced to miti-

gate these weaknesses (Ethereum Foundation, 2024b).

Post EIP-1559 (New Gas Model)

EIP-1559 introduced a new model of gas price where validators received only part of the gas price paid by users. The new mechanism split gas price into two components: the base fee and the priority fee.

The base fee is set by the Ethereum protocol and represents the minimum fee that will be accepted by the network and is therefore considered valid.

The priority fee is a tip that is added to the base fee to improve the queue position and increase the chance of inclusion in the next block.

The base fee is dynamically adjusted by the protocol to respond to the level of network congestion. It is determined by a formula which compares the gas value for all the transactions in the previous block with the target gas for one block. The target gas for one block is set by the protocol and currently is 15 million gas. The adjustment of the new base fee is capped at a 12.5% increase or decrease from the fee of the current block. The formula for the base fee is written as follows:

$$\begin{aligned} \text{New Base Fee} \\ = \text{Current Base Fee} \times \left(1 + \frac{\text{Gas Used} - \text{Target Gas Used}}{\text{Target Gas Used}} \times 12.5\% \right) \end{aligned}$$

The base fee does not go to the validators; instead, it is burned when the transaction is completed. On the other hand, the priority fee will be paid to the validators as an incentive to process the transaction. In this mechanism, the base fee becomes the determining factor for a transaction to be processed.

The following summarizes key differences between the pre- and post-EIP-1559 mechanisms (Ethereum Foundation, 2024b).

Fee Structure:

Pre-EIP-1559: Single gas price bid set by the user, paid entirely to miners.

Post-EIP-1559: Dual fee structure with a base fee that is burned and a priority fee that is paid to validators.

Fee Adjustment Mechanism:

Pre-EIP-1559: Gas prices are entirely market-driven, often leading to volatility and unpredictability.

Post-EIP-1559: Base fee is dynamically adjusted, with a cap, based on network congestion, providing more predictability.

User Experience:

Pre-EIP-1559: Users had to overbid to ensure that transactions were included quickly, potentially leading to overpayment.

Post-EIP-1559: Users set a maximum fee, protecting them from overpaying during network congestion.

3. Research Question

The aim of this paper is to investigate the relationship between gas price and us-

er activity and whether the changes introduced by EIP-1559 in the gas price calculation mechanism and the increasing ETH price have resulted in changes to this relationship, compared to previous findings pre-EIP-1559. The results are useful to gain insights into how users adjust their activity in response to these changes.

This paper uses the number of pending transactions as a representation of user activity, the same indicator used in the previous study (Pierro & Rocha, 2019). Technically, because there is a limit to the number of transactions that can be confirmed in a block, the number of confirmed transactions in a well-utilized blockchain, such as Ethereum, will be roughly constant and, therefore, not a good reflection of user activity. However, pending transactions are not subject to such a limitation since transactions that do not fit into the current block are left pending for the next. Therefore, they are a more suitable indicator of user activity than the number of confirmed transactions.

This approach will be used to answer the main research question: Does the relationship between gas price and user activity that was observed prior to EIP-1559 still hold after EIP-1559?

4. Data Collection and Analysis Methods

Justification of the data collection interval

Every submitted transaction to an Ethereum node contains the following information, which users must decide and input (Ethereum Foundation, 2024a):

The address of the sender.

The destination address.

The cryptographic signature of the sender. This is generated when the transaction is signed using the sender's private key, confirming the sender's authorization of the transaction.

The nonce, which is a unique and sequentially increasing identifier assigned to each transaction sent by the user.

The amount of ETH to be transferred from sender to recipient.

Optional data.

The gas limit, which is the maximum amount of gas that can be expended in completing the transaction. This depends on the level of complexity of the transaction.

The maximum priority fee, which is the maximum tip a user is willing to pay to validators for prioritizing their transaction. This fee, in conjunction with the base fee and the maximum gas price determines the total transaction cost, ensuring users can expedite transactions while maintaining cost predictability.

The maximum gas price, which is the maximum total fee the user is willing to pay for the transaction, which includes the base fee and the priority fee.

To transact on the Ethereum network, the majority of users use a wallet on a web browser or a smartphone (Yu Qian, 2023). An interval of 1 minute was chosen because the author estimates that, on a web browser or smartphone, it

takes about 1 minute to complete all the above steps before deciding to submit the transaction after knowing the applicable gas price. In addition, the previous study (Pierro & Rocha, 2019) also found that the gas price Granger causes user activity when the number of lags exceeds 6, or slightly above 1 minute.

Methods for Data Collection

This study uses Dune Analytics (Dune Analytics, 2024) via SQL querying as the main data source for acquiring the time series of gas prices, the number of pending transactions, and Ethereum prices, all within the Ethereum network. Datapoints were taken at 1-minute intervals. The dataset covers the period from December 1, 2023, 00:00:00 to December 15, 2023, 23:59:00.

Dune Analytics is a platform for exploring, analyzing, and visualizing blockchain data. It has an extensive suite of tools that allow users to query and interpret data from various blockchain networks. The platform allows users to create custom queries using SQL.

In terms of the gas price, this study uses Dune Analytics' `min_gas` reading, which is the minimum gas accepted by the network. The previous study (Pierro & Rocha, 2019) used the minimum gas price accepted by all top miners. The `min_gas` statistic is comparable to the gas price used in the previous study, as it also represents the minimum gas price that allows for the transaction to be successfully executed.

In the period considered in this paper, gas prices ranged from 19 Gwei to 332 Gwei. One Gwei is 10^{-9} ETH.

Pearson Correlation Test

The Pearson correlation test is a calculated statistical index that shows the strength and direction of a linear correlation between two continuous sets of data (Freedman, Pisani, & Purves, 2007). It produces a correlation coefficient, denoted by "R", which ranges from -1 to 1. When the correlation is 1, it suggests a perfect positive linear relationship. When it is -1, it suggests a perfect negative linear relationship, and a correlation of 0 indicates no such relationship between the variables.

The test assesses how well a straight line can describe the relationship between the variables. It is crucial to note that correlation does not imply causation; it only measures how closely the two variables move together.

In this study, the Pearson coefficient was calculated between simultaneous data points of two variables: the gas price, and the number of pending transactions. This is to investigate the relationship and interplay between the two.

Augmented Dickey-Fuller Test

The Augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1979) is specifically designed for time series data analysis to reveal the statistical stationarity of a given time series. Stationarity is a key concept in time series analysis, characterized by the relative stability of several statistical properties, including mean, variance, and autocorrelation (Statistics Solutions, 2024).

The ADF test helps in assessing the stationarity of a time series by examining

the presence of a unit root. By performing the ADF test and accepting the null hypothesis, which is that there is no unit root, it confirms that the time series is stationary. This allows for more reliable statistical analysis, modelling, and forecasting, which is a requirement for the Granger causality test.

Granger Causality

Granger Causality is a statistical approach used to evaluate if one time series can predict another (Granger, 1969, 1981), and helps in establishing a causal relationship between the two. It does so by determining the ability of past values of one variable to forecast future values of another variable. In summary, if variable X Granger causes variable Y , then past values of X should hold information that helps predict Y .

This test is used to examine, in both directions, the causal relationship between user activity and gas price.

Key Equations (Granger, 1969, 1981)

The two time series analyzed in this study are that of Gas Price G_t and User Activity A_t . Then, the Granger Causality test estimates the following two regressions:

Unrestricted Model:

$$A_t = \alpha_0 + \sum_{i=1}^p \alpha_i A_{t-i} + \sum_{j=1}^q \beta_j G_{t-j} + \epsilon_t$$

where α_0 is a constant, α_i and β_j are coefficients, and ϵ_t is the error term.

Restricted Model:

$$A_t = \alpha_0 + \sum_{i=1}^p \alpha_i A_{t-i} + u_t$$

where u_t is the error term.

The null hypothesis (H_0) for the Granger Causality test is that G does not Granger-cause A , which mathematically translates to:

$$H_0 : \beta_1 = \beta_2 = \dots = \beta_q = 0$$

Test Procedure (Granger, 1969, 1981)

1) Fit the unrestricted and restricted models using ordinary least squares (OLS) to estimate both models.

2) Compute F-Statistic to compare the fit of the two models:

$$F = \frac{(RSS_r - RSS_u)/q}{RSS_u/(N-k)}$$

where RSS_r and RSS_u are the residual sum of squares of the restricted and unrestricted models, respectively. In the above equation, q is the number of lagged G terms, N is the number of observations, and k is the total number of parameters estimated in the unrestricted model. k was denoted under *Key Equations* as p and q , the degree of the polynomial.

3) Decision Rule: If the F-statistic exceeds the critical value from the

F-distribution, reject the null hypothesis. This indicates that G Granger-causes A .

This test was used to examine the causal relationship between the gas price and user activity. The same test was also performed in the opposite direction: from A to G .

These three tests—Pearson, ADF, and Granger causality—were performed with gas price both in ETH and US\$. The results for US\$ are shown in section 5. Analysis for gas price in ETH yielded very similar results.

The datasets and results of analysis are publicly available on: <https://drive.google.com/drive/folders/105IhHOX7PsT34b5r14GMd-0Qq4uwtG-u>

5. Results and Discussion

The datasets for pending transactions, gas price in ETH, ETH price in US\$, and gas price in US\$ each contain 21,601 observations and are shown in **Figures 1-4** respectively.

Figure 1 indicates that during the data collection period, pending transactions were prevalent, suggesting that transaction volume exceeded block capacity most of the time. The peak number of pending transactions, 1243, occurred on December 15 at 08:02. Although extremely high transaction volumes are often associated with activities like ICOs and IDOs (Faqr-Rhazoui, Ariza-Garzón, Arroyo, & Hassan, 2021), there were no reports of such events during this period (ICODrops, 2024).

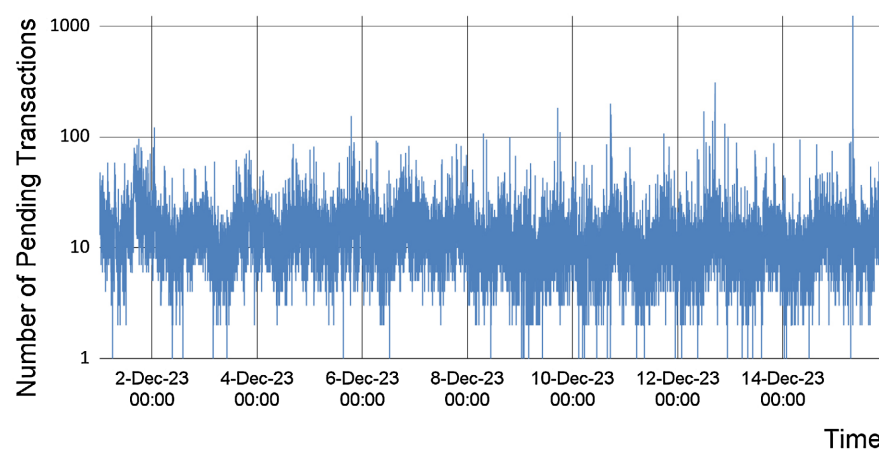


Figure 1. User activity (log scale) represented by the number of pending transactions.

Figure 2 shows the gas price in ETH over time, with the highest recorded gas price of 332 Gwei on December 1st at 11:37 and the lowest of 19 Gwei on December 11th at 00:16. The mean gas price is 42 Gwei.

Figure 3 presents a graphical representation of the raw data collected, depicting the ETH price in US\$ over time. The highest price, US\$ 2396.65, was recorded on December 9th at 08:30, while the lowest price, US\$ 2046.20, occurred on

December 1st at 00:30. The price trend shows a step-like pattern of increases and decreases, with the overall fluctuation remaining within a relatively narrow range of approximately 13%.

Figure 4 illustrates the gas price in US\$ over time, with the lowest recorded

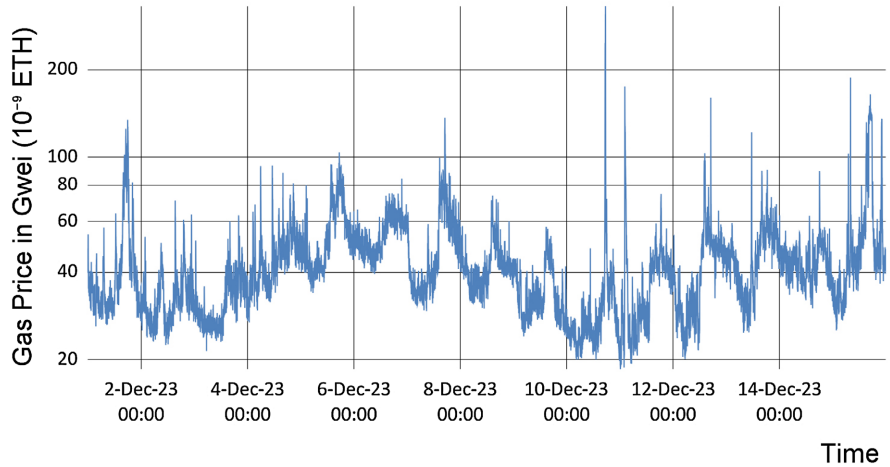


Figure 2. Gas price in ETH (log scale).

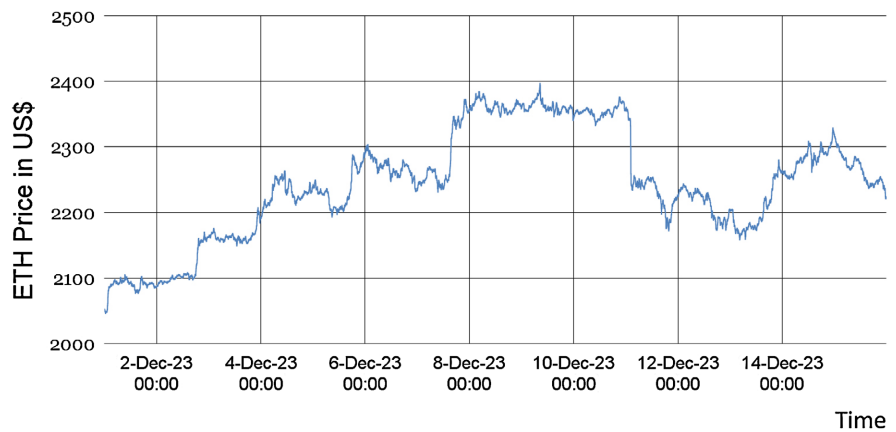


Figure 3. Ethereum Price during the observed period (US\$).

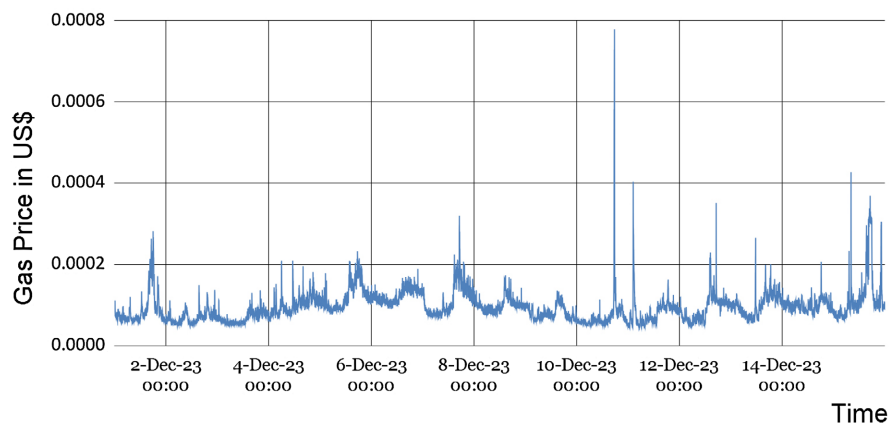


Figure 4. Gas price in US\$.

value of US\$ 0.0000435 on December 11th at 05:18 and the highest value of US\$ 0.000778 on December 10th at 17:33. The mean value of the gas price is US\$ 0.0000953.

A statistical summary of the collected data is shown below in **Table 1**.

Table 1. Statistical Description of Data on 1-15 Dec 2023.

	Gas Price (Gwei or 10^{-9} ETH)	User Activity	ETH Price (US\$/ETH)	Gas Price (10^{-5} US\$)
Mean	42	14	2244.13	9.53
Std. Dev	17	13	82.95	3.82
Min	19	0	2046.20	4.35
50% ^a	40	12	2246.03	9.01
75% ^b	49	16	2298.60	10.97
95% ^c	69	27	2365.19	15.60
99% ^d	104	48	2375.65	23.00
Max	332	1,243	2396.65	77.86

^a50th percentile, ^b75th percentile, ^c95th percentile, ^d99th percentile.

Statistical analysis on user activity were performed with gas price in both Gwei (10^{-9} ETH) and US\$.

Pearson Correlation

To understand the relationship between gas prices and user activity, Pearson correlation tests were conducted, yielding a coefficient of 0.1887 for gas price in Gwei (10^{-9} ETH) and a coefficient of 0.0356 for gas price in US\$ (see **Table 2**). This correlation coefficient suggests that while the variables sometimes move together, the association is weak.

Table 2. Pearson correlation value.

Gas Price (Gwei or 10^{-9} ETH) vs User Activity	Coefficient Value
R	0.1887
R ²	0.0356
User Activity vs Gas Price (US\$)	Coefficient Value
R	0.1780
R ²	0.0317

Augmented Dickey-Fuller Test

An ADF test was performed to confirm the stationarity of the series. The ADF test results show that both data series—gas price and pending transactions—were stationary. The ADF test results are summarized in **Table 3**.

The ADF test, therefore, indicates that the data series is suitable for the Granger Causality test due to the lack of a unit root.

Table 3. ADF test results.

Variables	ADF Stats.	p-value	Critical Value 1%	Conclusion
Gas price (Gwei)	-39.731	0.0000	-3.9714	Stationarity
User Activity	-51.383	0.0000	-3.9714	Stationarity
Variables	ADF Stats.	p-value	Critical Value 1%	Conclusion
Gas Price (US\$)	-39.914	0.0000	-3.9714	Stationarity
User Activity	-51.383	0.0000	-3.9714	Stationarity

Granger Causality Test

The results in **Table 4** show that the gas price Granger causes user activity, because the p-value (0.0000) is significant.

Table 4. Granger Causality Test Results

Null Hypothesis	F-statistic	p-value	Decision
Gas Price (Gwei) does not Granger cause User Activity	10.7591	0.0000	Rejected
User Activity does not Granger cause Gas Price (Gwei)	44.1093	0.0000	Rejected
Null Hypothesis	F-statistic	p-value	Decision
Gas Price (US\$) does not Granger cause User Activity	10.7874	0.0000	Rejected
User Activity does not Granger cause Gas Price (US\$)	44.1788	0.0000	Rejected

The study found a bidirectional causal relationship between gas price and user activity.

Discussion

The previous study (Pierro & Rocha, 2019) conducted prior to EIP-1559 reported a moderate to strong negative Pearson correlation coefficient of -0.6 , suggesting that increases in gas prices led to decreased user activity. It was reasoned that users were delaying their transactions to avoid overpayment. Regarding the implementation of EIP-1559, this observation can be further understood: pre-EIP-1559, there was no predictability in gas prices because miners independently determined the minimum gas price, and there was no maximum gas fee to limit how much users would pay for their transactions, thus increasing the risk of overpayment.

In contrast, this study reveals a shift: a weak positive Pearson correlation coefficient of 0.1887 , indicating that increases in gas prices do not lead to decreased user activity. It is possible that EIP-1559 has enhanced user confidence through its gas price determination. This, in turn, influences users' decision-making. Specifically, users are generally more assured in continuing their transactions under the new mechanism, as can be shown from the observation that a raise in gas prices does not cause user activity to decrease.

Furthermore, this study observed a new phenomenon: Granger causality in which an increase in user activity causes slight increases in gas price. This was

not present in the previous study and is likely a result of the new gas price formula introduced by EIP-1559, which takes into account the level of user activity on the network as well as the price adjustment cap. This formula has introduced a predictable link between user activity dynamics and gas price, thereby providing greater certainty for users.

The results of the Pearson correlation and Granger causality analyses are very similar whether gas prices are denominated in ETH or US\$. This suggests that Ethereum users are not sensitive to conversion rates between ETH and US\$.

The results of this study represent normal conditions, as specific events such as ICOs and IDOs were not found during the study period (ICODrops, 2024). This is important to know because this study observed that user activity did not decrease even when gas prices increased, a phenomenon usually seen during events like ICOs and IDOs where users compete to get their transactions executed in anticipation of profit (Faqir-Rhazoui et al., 2021).

6. Summary and Conclusions

The results of this study show a weak positive Pearson correlation and a bidirectional Granger causality between gas price and user activity.

The statistically causal effect of gas price to user activity with weak positive correlation can be attributed to increases of users' confidence because of more transparent and predictable gas price calculations due to EIP-1559.

The causal effect of user activity to gas price can be explained by the explicit inclusion of user activity in the formula of gas price determination in EIP-1559.

This study gives a timely update on the state of transaction economics in Ethereum and focuses on the effects of EIP-1559. The study reveals shifts between pre-EIP-1559 and post-EIP-1559 datasets, as well as offers explanations. It appears that EIP-1559 offers confidence, in terms of gas price determination, to users. This in turn has affected the way that users make decisions—they usually still submit transactions for a spot on the block, regardless of increases in gas price. These findings and suggestions are therefore of interest to Ethereum blockchain economics. This study adds a new perspective to previous research on similar themes.

Between the previous study and this study, EIP-1559 resulted in significant changes in the determination of gas prices on the Ethereum network due to its direct redefinition of gas price setting. Other changes, such as the switching of consensus mechanisms from Proof-of-Work (PoW) to Proof-of-Stake (PoS), although indirect, may also have influenced the relationship between gas prices and user activity, making it a valuable area for future research.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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