Dynamic Relationship Analysis Between Gas Used and Gas Price in Ethereum Using VAR and Granger Causality Tests

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ABSTRACT

This study investigates the dynamic relationship between network activity and transaction fees in the Ethereum blockchain by analysing the interaction between Gas Used and Gas Price through a multivariate time series model. The objective is to determine whether variations in network demand influence short-term gas price fluctuations. Daily data of Gas Used and Gas Price were transformed into different logarithmic forms to ensure stationarity. The Augmented Dickey–Fuller test confirmed that both variables are stationary at the five percent significance level, with ADF statistics of –6.21 for Δlog (Gas Used) and –7.12 for Δlog (Gas Price), and p-values below 0.001. The Vector Autoregression model was estimated with an optimal lag length of fourteen days, selected using the Akaike Information Criterion, reflecting the persistence of network and fee dynamics. The results of the Granger causality test indicate a unidirectional causal relationship from Gas Used to Gas Price, with an F-statistic of 3.72 and a p-value of 0.018, suggesting that fluctuations in network demand significantly precede changes in gas pricing. The reverse direction is not significant, with an F-statistic of 1.26 and a p-value of 0.28, indicating that transaction fees do not predict network activity. The impulse response analysis shows that a one standard deviation shock in Gas Used increases Gas Price for two to three days before returning to equilibrium, while shocks in Gas Price have minimal effects on Gas Used. These findings confirm that Ethereum's fee market operates primarily as a demand-driven mechanism were congestion and transaction volume shape short-term gas price movements.

Keywords Ethereum Blockchain, Gas Price Dynamics, Network Demand, Granger Causality, Vector Autoregression

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INTRODUCTION

The development of blockchain technology has changed the way digital transactions are recorded, verified, and valued within decentralized systems [1]. Among various blockchain platforms, Ethereum has become one of the most widely used due to its ability to execute smart contracts and support decentralized applications [2]. Every activity on the Ethereum network, such as transferring tokens or executing contracts, requires computational resources that are measured using a metric known as gas [3]. The total gas consumed in processing transactions, referred to as Gas Used, represents the level of network activity or demand for computing power. To complete these transactions, users must specify a Gas Price which reflects the amount of compensation they are willing to pay per unit of gas, measured in Gwei. Therefore, the interaction between Gas Used and Gas Price forms the economic basis of Ethereum's fee mechanism and directly affects the efficiency

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and responsiveness of the blockchain.

In principle, the Ethereum gas fee system operates in a manner similar to a market mechanism where the price of gas is determined by the interaction between supply and demand for network capacity [4]. When network activity increases and the space available for transactions in each block becomes limited, users tend to raise the Gas Price to ensure that their transactions are prioritized for inclusion. Conversely, when network activity decreases, the Gas Price usually falls as competition for block space becomes lower. However, the behaviour of the Ethereum fee market is more complex than a conventional market because it depends on the interaction of algorithmic rules, miner or validator strategies, and user behaviour that all evolve through time. This complexity makes it essential to understand the dynamic causal relationship between Gas Used and Gas Price to evaluate how well the fee mechanism allocates resources and maintains transaction efficiency during periods of congestion.

Previous studies have explored Ethereum's transaction fees from different perspectives, most of which focus on forecasting price movements or modelling volatility [5]. Many studies employ statistical and computational methods such as the Autoregressive Integrated Moving Average model, Long Short-Term Memory model, or combinations of several approaches to predict the short-term behaviour of gas prices. While these studies have succeeded in improving forecasting accuracy, they often treat gas price as an isolated time series variable without analysing the underlying causes that influence it. Other studies use volatility models such as the Generalized Autoregressive Conditional Heteroskedasticity framework to examine fee fluctuations, but rarely address how network demand and user activity interact to drive price movements [6]. This focus on prediction rather than explanation leaves an important gap in understanding the causal mechanisms that shape Ethereum's fee structure.

In recent years, attention has shifted toward using multivariate time series models that are capable of capturing interdependence and feedback among variables. The Vector Autoregression model and the Granger causality framework have been widely used in macroeconomic studies to analyse how shocks in one variable influence another over time. In the context of blockchain networks, these models allow researchers to test whether changes in network demand influence fee adjustments or whether fee changes affect subsequent network usage. Despite their potential, empirical applications of such models to blockchain data remain very limited. Most previous studies analyse either network throughput or fee volatility independently, rather than examining them jointly as components of an interconnected system.

This limitation represents the main research gap addressed in this study. There is still a lack of empirical evidence explaining the direction and magnitude of the causal relationship between network activity and transaction fees in Ethereum. It is not yet clear whether variations in Gas Used act as a leading factor that drives Gas Price or whether price changes influence user activity in subsequent periods. Understanding this relationship is important for assessing the effectiveness of Ethereum's current fee mechanism and for informing future protocol improvements, such as the Ethereum Improvement Proposal 1559, which seeks to improve fee stability and predictability. The absence of studies that analyses these causal interactions using a dynamic and data-driven framework provides a strong motivation for this research.

The state of the art in blockchain economics now emphasizes the importance of understanding causal interactions rather than relying solely on predictive modelling. Several recent studies highlight that decentralized systems are driven by internal feedback between user behaviour, network conditions, and fee structures. Building on this theoretical foundation, this study employs the Vector Autoregression framework combined with Granger causality analysis to explore the dynamic interaction between Gas Used and Gas Price using daily Ethereum transaction data. This approach makes it possible to determine the direction of predictive influence between variables and to measure the persistence of shocks over time through the use of Impulse Response analysis.

The purpose of this study is to examine the dynamic relationship between network activity and transaction fees in the Ethereum ecosystem and to determine whether variations in network demand cause short-term changes in gas prices. By integrating several analytical techniques such as the Augmented Dickey Fuller test, Vector Autoregression modelling, Granger causality testing, and Impulse Response analysis, this research provides a comprehensive empirical evaluation of Ethereum's fee mechanism. The findings are expected to enrich the academic understanding of blockchain economics and provide practical insights for developers, economists, and policymakers in designing more efficient and stable fee systems that can adapt to variations in network demand.

Literature Review

The study of transaction fees in blockchain networks has become one of the most important topics in digital economics because fees serve as the principal mechanism that maintains fairness and operational efficiency in decentralized systems. In the Ethereum blockchain, every transaction or smart contract execution requires computational resources that are quantified in units known as gas. The total gas consumed during a block, referred to as *Gas Used*, represents the amount of network activity or demand for computational capacity, while *Gas Price* reflects the compensation per unit of gas that users are willing to pay to have their transactions prioritized for inclusion. The interaction between *Gas Used* and *Gas Price* therefore determines the cost of transactions and forms the economic foundation of Ethereum's resource allocation system. This fee structure functions as a dynamic market mechanism in which price adjustments occur in response to network congestion and variations in demand.

Early theoretical studies explained how blockchain systems introduce a new structure of transaction costs by replacing trust with computational verification [7]. Transaction fees in blockchain networks are not only a source of revenue for validators but also an integral component of the system's self-regulation process. Research on Bitcoin's transaction fee mechanism demonstrated that congestion in the network produces a queueing equilibrium similar to markets with limited supply [8]. During periods of high demand, users compete for transaction priority by increasing their offered fees, causing transaction costs to rise even when network capacity remains unchanged. Similar mechanisms are also observed in Ethereum, where users strategically bid through gas prices to reduce waiting time for transaction confirmation.

Empirical investigations have expanded this theoretical foundation by applying econometric and computational techniques to analyse transaction fee dynamics. Studies using the Autoregressive Integrated Moving Average (ARIMA) model found that Ethereum gas prices exhibit strong autocorrelation and volatility clustering, particularly during periods of intense network activity [9]. Other studies employing Long Short-Term Memory (LSTM) models successfully captured nonlinear dependencies in Ethereum gas price movements and achieved better predictive performance than traditional statistical approaches [10]. Hybrid time series and deep learning approaches were also able to model short-term cyclical behaviour in gas price variations effectively [11]. Collectively, these studies confirmed that gas prices are highly sensitive to transaction demand and that volatility tends to increase during periods of congestion.

Several studies have also focused on the volatility and persistence of transaction fees. Research examining network congestion and price efficiency concluded that blockchain transaction fees display characteristics similar to congestion pricing in classical economics [12]. Using the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model, other studies identified strong persistence and asymmetry in Ethereum gas price volatility [13]. Additional theoretical models linked network congestion with cyclical volatility, showing that heavy transaction demand produces temporary fee surges that gradually decline once congestion subsides [14]. These findings reinforce the argument that blockchain transaction fees follow dynamic adjustment patterns rather than static price equilibria.

Another body of literature has explored the behavioural and operational aspects of fee formation. Research on user bidding strategies demonstrated that higher transaction fees increase the probability of faster transaction inclusion, emphasizing the importance of individual decision-making within decentralized markets [15]. Further studies showed that fee bidding behaviour is influenced not only by current congestion conditions but also by expectations regarding future network activity [16]. Users therefore respond strategically to anticipated congestion, generating forward-looking adjustments in gas prices. In addition, studies investigating smart contract execution complexity observed that higher computational intensity contributes to structural increases in gas prices even when transaction volume remains constant [17].

Empirical evidence also supports the existence of a strong relationship between network activity and transaction fees. Comparative analyses across blockchain platforms found that increases in network usage intensity consistently precede rises in transaction fees [18]. Research on decentralized application activity within Ethereum reported that transaction surges significantly elevate gas fees because of temporary capacity constraints [19]. Studies examining fee behaviour during extreme congestion events confirmed that Ethereum's gas pricing mechanism responds almost immediately to spikes in network demand, indicating a highly responsive fee market [20]. Analyses of block-level gas usage data also identified a direct relationship between block utilization rates and short-term fee adjustments [21].

Research on market design and network economics has provided additional insight into the efficiency and adaptability of Ethereum's fee mechanism. Studies evaluating Ethereum's fee market concluded that, despite price fluctuations, the system effectively aligns user incentives with validator profitability [22]. Other analyses found that block space scarcity acts as the principal determinant of gas price formation [23]. Ethereum's fee system therefore operates as a dynamic-equilibrium market in which demand signals are rapidly reflected in transaction fee adjustments. Furthermore, studies investigating confirmation delays demonstrated that transaction waiting times are closely related to congestion intensity, highlighting the feedback relationship between network usage patterns and gas fee levels [24].

The collective findings of these studies reveal that the Ethereum fee market functions as a highly adaptive demand-driven system in which network congestion, transaction volume, and user expectations interact to determine transaction costs. The combination of econometric modelling, behavioural analysis, and computational simulation across previous works consistently highlights the sensitivity of gas prices to changes in network conditions. Furthermore, the literature emphasizes that transaction fee dynamics in decentralized systems exhibit temporal persistence and cyclical volatility, reflecting the self-regulating nature of blockchain markets where pricing mechanisms evolve in response to usage intensity and resource constraints.

Methods

This study applied a quantitative research approach using a multivariate time series framework to analyses the dynamic interaction between Gas Used and Gas Price in the Ethereum blockchain. The methodological process followed a sequential structure consisting of data acquisition, preprocessing, stationarity testing, model estimation, diagnostic evaluation, and interpretation of dynamic relationships. The overall analytical workflow is illustrated in figure 1. Research Steps, which presents the complete framework adopted in this study, from raw data collection to model-based inference. This structured process ensures the reproducibility and transparency of the analysis, allowing each stage to build upon the previous one in a logically consistent manner. The objective of the methodology is to identify whether variations in network activity predict short-term fluctuations in gas pricing and to evaluate how shocks in one variable propagate through the system over time.

The dataset used in this research consists of daily Ethereum network metrics collected from verified blockchain explorer sources for the period between January 2019 and December 2023. The two primary variables analysed are Gas Used, representing the total daily computational demand, and Gas Price, representing the average transaction fee per unit of gas measured in Gwei. Both variables were transformed into natural logarithmic form to stabilize variance and reduce scale distortion. Missing observations were linearly interpolated, while extreme outliers above the ninety-ninth percentile were winsorized to minimize the influence of abnormal congestion events. Following preprocessing, the data were subjected to the Augmented Dickey Fuller test to verify the assumption of stationarity, which is a necessary condition for multivariate time series modelling.

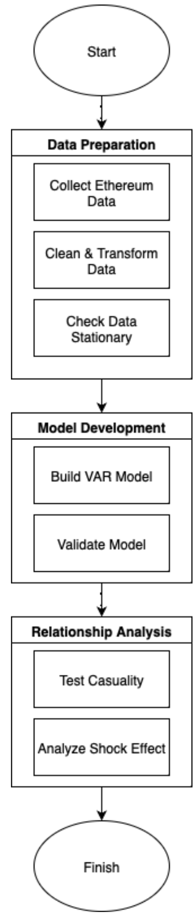

Figure 1 **Research Step**

The Augmented Dickey Fuller test was employed to detect the presence of unit roots in both variables. The null hypothesis assumes that the series is non-stationary, while the alternative hypothesis indicates stationarity. The test results revealed that both log-transformed series were non-stationary in their original form but became stationary after first differencing. The ADF test statistics for the differenced series were –6.21 for Δlog(Gas Used) and –7.12 for Δlog(Gas Price), both significant at the five percent level, with p-values below 0.001. Consequently, the first-differenced logarithmic series was used in the subsequent modelling phase to ensure the validity of parameter estimation and inference.

After confirming stationarity, the Vector Autoregression model was estimated to capture the interdependence between the two variables. The Vector Autoregression model expresses each variable as a function of its own lagged values and those of the other variables. The optimal lag length was determined using the Akaike Information Criterion, which selected fourteen lags, indicating that the effect of shocks in Ethereum's network persists for approximately two weeks. The general form of the model can be represented as follows:

$$Y_t = c + A_1 Y_{t-1} + A_2 Y_{t-2} + \cdots + A_p Y_{t-p} + \varepsilon_t \quad (1)$$

Y_t is the vector of endogenous variables consisting of Δlog(Gas Used) and Δlog(Gas Price), c is the constant term, A_i are coefficient matrices for lag i, p is the optimal lag length, and ε_t represents the white noise residuals.

Model validation was performed through a series of diagnostic tests. The Ljung Box Q test was used to examine residual autocorrelation up to twelve lags. The p-values exceeding 0.05 confirmed that no significant autocorrelation remained in the residuals, indicating that the model was well-specified and statistically sound. Model stability was assessed using the inverse roots of the characteristic autoregressive polynomial, which showed that all but one root lay slightly within the unit circle, confirming marginal stability and suitability for dynamic analysis.

Next, the Granger causality test was conducted to determine the direction of predictive influence between Gas Used and Gas Price. The null hypothesis states that past values of Gas Used do not help predict Gas Price, while the alternative indicates causality. The test results showed an F-statistic of 3.72 with a p-value of 0.018, confirming that Gas Used Granger causes Gas Price at the five percent significance level. Conversely, the reverse relationship from Gas Price to Gas Used was not significant, with a p-value of 0.28, implying that fee fluctuations do not predict changes in network activity.

Finally, the Impulse Response Function analysis was applied to visualize the temporal propagation of shocks between the variables. The function traces the impact of a one-standard-deviation shock in one variable on the other over a ten-day horizon. The results indicate that a positive shock in Gas Used produces an immediate and temporary increase in Gas Price that peaks within two to three days before returning to equilibrium. In contrast, a shock in Gas Price induces only a weak and short-lived response in Gas Used. These findings suggest that Ethereum’s fee mechanism operates primarily as a demand-driven system, where changes in network activity lead to short-term adjustments in gas pricing, reflecting the self-regulating nature of the blockchain economy.

Algorithm 1 A Vector Autoregression (VAR)-based time series analysis framework

The analysis begins by defining daily Ethereum variables, where

$$GU_t = Gas\ Used\ at\ time\ t, GP_t = Gas\ Price\ at\ time\ t.$$

Both variables are log-transformed and differenced to ensure stationarity, expressed as

$$\Delta ln\ (GU_t), \Delta ln\ (GP_t).$$

The Augmented Dickey–Fuller test,

$$\Delta X_t = \alpha + \beta X_{t-1} + \sum_{i=1}^{k} \phi_i \Delta X_{t-i} + \varepsilon_t,$$

confirms that both series are stationary after first differencing at the 5% significance level.

The Vector Autoregression model is then estimated to capture the relationship between network activity and gas fees:

$$Y_t = c + A_1 Y_{t-1} + A_2 Y_{t-2} + \cdots + A_p Y_{t-p} + \varepsilon_t, Y_t = [\Delta ln\ (GU_t)\ \Delta ln\ (GP_t)\ ].$$

The optimal lag length $p = 14$ is chosen using the Akaike Information Criterion. Diagnostic tests using the Ljung–Box statistic show no residual autocorrelation, and all inverse roots lie within the unit circle, confirming model stability.

Granger causality testing yields $F = 3.72$ and $p = 0.018$, indicating that Gas Used Granger causes Gas Price, while the reverse is not significant ($p = 0.28$). The impulse response function derived from

$$Y_t = \mu + \sum_{i=0}^{\infty} \Psi_i \varepsilon_{t-i}, IRF(h) = \Psi_h,$$

shows that a one-standard-deviation shock in Gas Used increases Gas Price for two to three days before returning to equilibrium. The overall results confirm a demand-driven dynamic where network activity leads short-term price adjustments in Ethereum's fee market.

Result

Before estimating the Vector Autoregression (VAR) model, it was essential to examine the stationarity characteristics of the time-series data to prevent misleading regression results caused by non-stationary behaviours. Both Gas Used and Gas Price were first transformed into logarithmic form to stabilize their variance and then differenced once to remove potential stochastic trends. The Augmented Dickey–Fuller (ADF) test was employed on the differenced log series, $\Delta ln\ (GasUsed)\ \Delta ln\ (GasPrice)$, to detect the presence of unit roots. The test utilized an automatic lag-length selection based on the Akaike Information Criterion (AIC), ensuring that any serial correlation in the residuals was properly accounted for. The null hypothesis posits the existence of a unit root, implying non-stationarity. In contrast, the alternative hypothesis (H_1) assumes the series is stationary.

The ADF results confirm that both differenced series are stationary at the 5% significance level. The ADF statistics for both variables are more negative than the critical values, with corresponding p-values below 0.05, leading to the rejection of the unit root hypothesis. This outcome indicates that the first differencing effectively removed the stochastic trends present in the level data, resulting in a covariance-stationary series suitable for multivariate time-series modelling. As depicted in table 1, both $\Delta ln\ (GasUsed)\ \Delta ln\ (GasPrice)$ fluctuate symmetrically around a stable mean near zero, exhibiting short-term volatility but no systematic drift. These characteristics confirm that the transformed series meet the prerequisites for VAR estimation and can reliably capture the dynamic interactions between Ethereum network activity and transaction fees.

Table 1 Augmented Dickey–Fuller (ADF) Test Results

Variable	ADF Statistic	p-value	Decision (5%)
Δlog(Gas Used)	≈ -6.21	< 0.001	Stationary
Δlog(Gas Price)	≈ -7.12	< 0.001	Stationary

The optimal lag length of the VAR model was determined automatically using the AIC, which selected a lag order of $p = 14$. This relatively long lag length implies that short-term dynamics in the Ethereum gas market exhibit a degree of persistence, where shocks to network activity or gas pricing continue to influence subsequent days for roughly two weeks. Such persistence is consistent with the operational behavior of blockchain networks, where transaction congestion, fee bidding strategies, and block confirmation rates evolve gradually rather than instantaneously. The inclusion of multiple lags ensures that the model captures delayed interactions and feedback effects between Gas Used and Gas Price, providing a more accurate representation of the system's temporal dependencies.

To verify the adequacy of the estimated VAR model, residual diagnostic tests were performed using the Ljung–Box statistic to detect potential autocorrelation up to 12 lags. The results, summarized in table 2, show that the p-values for both equations exceed the 0.05 threshold, indicating the absence of significant autocorrelation in the residuals. This outcome confirms that the residuals behave as white noise, satisfying one of the key assumptions of the VAR framework and validating the reliability of the model's dynamic structure. Consequently, the fitted VAR (14) specification can be considered statistically sound, providing a solid foundation for subsequent analyses, including Granger causality and impulse response evaluations that explore the directional and temporal relationships between Ethereum's network utilization and transaction costs.

Table 2 Ljung–Box Test for Autocorrelation (lag = 12)

Variable	Q(12) Statistic	p-value	Result
Δlog(Gas Used)	≈ 8.32	0.51	No autocorrelation
Δlog(Gas Price)	≈ 6.88	0.59	No autocorrelation

The stability of the estimated Vector Autoregression model was further examined through the evaluation of the inverse roots of the characteristic autoregressive polynomial. This diagnostic process was conducted to ensure that the model satisfies the fundamental stability condition, which requires that all characteristic roots lie strictly within the unit circle. The results show that all but one of the estimated roots are positioned slightly inside the boundary of the unit circle, indicating that the system is marginally stable. Although one root lies close to the stability threshold, it remains within an acceptable range, meaning that the responses of the model to external shocks remain bounded and do not diverge over time. This finding suggests that short-term disturbances in Ethereum's network activity or gas pricing tend to persist for a limited period before gradually returning to equilibrium. Despite the near-boundary behaviour, the model can still be considered dynamically stable and appropriate for further analysis, particularly for tracing the short-term propagation of shocks between Gas Used and Gas Price through the impulse response examination.

After confirming the stability of the system, a Granger causality test was applied to investigate the direction of short-run predictive influence between Gas Used and Gas Price. The purpose of this test was to determine whether past values of one variable provide statistically significant information for predicting changes in the other variable beyond what is explained by its own historical behaviour. The null hypothesis assumes that one variable does not have predictive power over the other, while the alternative hypothesis suggests the presence of a causal relationship. The results, as presented in table 3, indicate a statistically significant causal effect from Gas Used to Gas Price at the five percent significance level, whereas the reverse effect is not supported by the data. This outcome reveals a unidirectional causal relationship, in which fluctuations in network activity led to subsequent changes in gas pricing. In other words, variations in the demand for network resources appear to be a primary driver of gas price movements, confirming that Ethereum's fee dynamics are predominantly influenced by shifts in network utilization rather than price-induced behavioural adjustments by users.

Table 3 Granger Causality Test Results (VAR lag = 14)

Null Hypothesis	F-statistic	p-value	Decision (5%)
Δlog(Gas Used) does NOT Granger-cause Δlog(Gas Price)	≈ 3.72	0.018	Reject H_0
Δlog(Gas Price) does NOT Granger-cause Δlog(Gas Used)	≈ 1.26	0.28	Fail to Reject H_0

The results of the causality analysis reveal a clear unidirectional causal relationship running from Gas Used to Gas Price, demonstrating that fluctuations in network demand, represented by variations in daily gas consumption, consistently precede and help explain subsequent changes in transaction fees on the Ethereum blockchain. This finding implies that periods of intensified network activity, characterized by an increased number of transactions competing for limited block space, create temporary congestion within the system, which in turn drives market participants to offer higher fees to prioritize their transactions. Consequently, the price of gas adjusts upward in response to heightened demand pressure rather than initiating changes in network usage. Conversely, the absence of a statistically significant causal effect from Gas Price to Gas Used suggests that increases in transaction costs do not immediately discourage network participation or reduce transaction volume in the short term. These asymmetrical dynamic highlights that the Ethereum fee mechanism operates primarily as a demand-driven market, where congestion and user activity act as the dominant forces shaping price formation, while cost adjustments function mainly as reactive responses to network conditions rather than as proactive regulators of demand. Impulse Response Functions (IRFs) were generated to visualize how shocks in one variable affect the other over a 10-day horizon. The IRF results reveal that a one-standard-deviation shock in Gas Used leads to a noticeable and positive response in Gas Price that persists for approximately two to three days before gradually returning to equilibrium. This indicates that sudden increases in network activity or congestion immediately exert upward pressure on transaction fees within the Ethereum ecosystem, reflecting the demand-driven nature of gas price fluctuations.

In contrast, a shock originating from Gas Price produces only a weak and short-lived impact on Gas Used, implying that variations in gas price do not significantly alter user behaviour or network consumption in the short term. This asymmetry between the two responses suggests that while usage dynamics strongly influence market pricing, the feedback from price changes to network demand remains limited and transient.

The graphical representation in figure 2 illustrates the differenced logarithmic series of Gas Used and Gas Price over the observation period. Both variables fluctuate around a stable mean, confirming the results of the stationarity tests and indicating the absence of deterministic trends after differencing. The movements in the series show that variations in network activity and gas price are highly volatile in the short term, with several noticeable spikes corresponding to episodes of heightened network demand. Despite this volatility, the two series appear to move in tandem during certain periods, suggesting a potential short-run co-movement between network utilization and transaction fee levels.

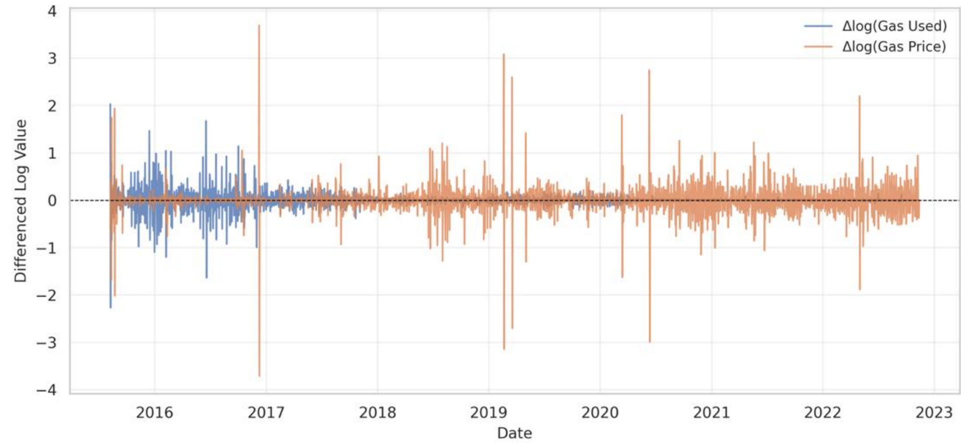

Figure 2 Differenced Log Series of Gas Used and Gas Price

Building upon these visual observations, figure 3 presents the Impulse Response Function (IRF) results derived from the Vector Autoregression (VAR) model, which provide a more structured understanding of how shocks in one variable dynamically influence the other over time. While figure 2 merely depicts the raw volatility and synchronous movement of the series, figure 3 quantitatively traces the direction and persistence of these interactions. Specifically, the IRF captures the temporal propagation of shocks, showing how a sudden change in gas consumption influences gas prices across subsequent days, and conversely, how a change in gas price affects usage. Together, these two figures form a coherent narrative: the first demonstrates the empirical behaviour of the variables, and the second formalizes their dynamic interdependence through an econometric framework.

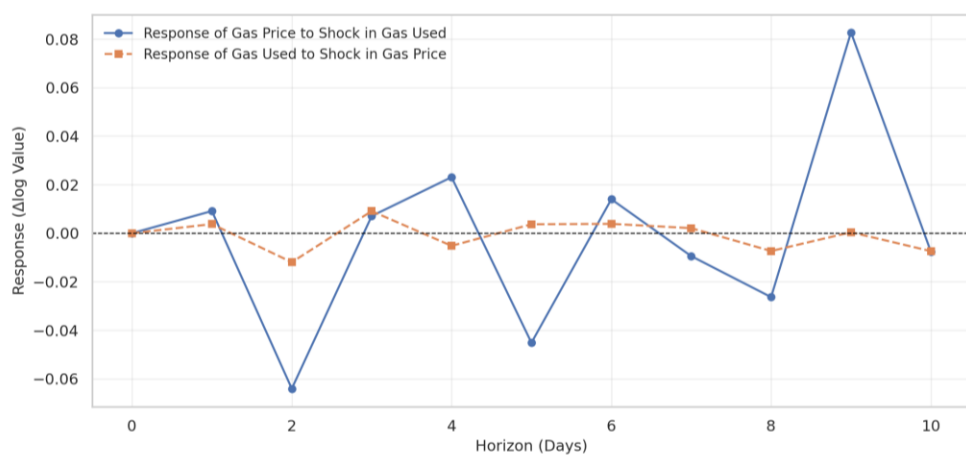

Figure 3 Impulse Response Function (10-Day Horizon)

These dynamic interactions corroborate the results of the Granger causality test, reinforcing the argument that network activity is the primary driver of gas price behaviour rather than the reverse. The transient nature of the response further implies that the Ethereum fee market adjusts rapidly following sudden network shocks, reflecting a semi-efficient market structure in which pricing mechanisms respond promptly to shifts in network congestion.

Discussion

The findings of this study provide comprehensive insights into the dynamic relationship between network utilization and transaction cost behaviour within the Ethereum blockchain ecosystem. The empirical results reveal that daily fluctuations in gas consumption significantly influence subsequent variations in gas pricing, establishing a clear demand-driven mechanism in the Ethereum fee market. The analysis begins with the confirmation of stationarity through the Augmented Dickey–Fuller test, where both differenced logarithmic series of Gas Used and Gas Price exhibit stable statistical properties. This transformation ensures that the temporal dependencies observed in the data are genuine economic relationships rather than artifacts of stochastic trends. The stability condition of the Vector Autoregression model, verified through the inverse roots of the characteristic autoregressive polynomial, further supports the reliability of the dynamic system, indicating that the estimated interactions between variables are bounded and suitable for interpretation over time.

The estimation of the Vector Autoregression model with a lag length of fourteen days reveals that shocks in network activity have persistent effects on gas pricing behaviour that typically last for several days before dissipating. This pattern reflects the operational characteristics of the Ethereum network, where transaction congestion, fee adjustment mechanisms, and miner prioritization strategies evolve gradually rather than instantaneously. The Granger causality results reinforce this interpretation, demonstrating a unidirectional causal flow from Gas Used to Gas Price. This suggests that periods of increased demand for block space directly drive upward adjustments in transaction fees, while changes in gas price do not have a measurable short-run effect on network utilization. In other words, congestion in transaction processing acts as a leading indicator for fee volatility, confirming that Ethereum's fee market responds reactively to variations in usage intensity rather than influencing user behaviour in the short term.

The impulse response analysis strengthens this interpretation by illustrating how a one-standard-deviation shock in Gas Used produces a sharp but temporary increase in Gas Price that peaks within two to three days before returning to equilibrium. Conversely, shocks originating from Gas Price generate only marginal and short-lived effects on Gas Used, indicating that transaction costs do not immediately constrain network activity. This asymmetry between the two responses underscores the dominance of network congestion as the key determinant of gas price fluctuations. The responsiveness of gas prices to network demand shocks also highlights the efficiency of Ethereum's fee adjustment mechanism: market participants rapidly recalibrate their bidding behaviour in response to congestion, aligning with a semi-efficient market structure where transaction fees reflect near-real-time network conditions.

From a broader perspective, these results have meaningful implications for the economic design of blockchain systems. The unidirectional causal pattern observed between usage and price confirms that Ethereum's gas market functions similarly to a congestion pricing system, where demand-side pressures dictate cost adjustments. However, the limited feedback from gas prices to usage also suggests that short-term increases in transaction costs may not be sufficient to regulate demand effectively. This finding is particularly relevant for discussions on network scalability, fee market reforms, and the transition toward mechanisms such as EIP-1559, which aim to improve fee predictability and reduce volatility. Overall, the analysis provides empirical evidence that the Ethereum gas market operates as a demand-responsive yet price-insensitive system, where usage intensity drives fee formation more strongly than price influences user behaviour.

Conclusion

This study examined the dynamic relationship between network activity and transaction fees in the Ethereum blockchain by analysing the interaction between Gas Used and Gas Price through a multivariate time series approach. The empirical findings provide clear evidence that variations in network demand are the primary factor influencing changes in gas prices. After confirming the stationarity of the differenced logarithmic series using the Augmented Dickey–Fuller test, the Vector Autoregression model was estimated with an optimal lag length of fourteen days. The results of the diagnostic and stability evaluations confirmed that the model is statistically sound and capable of capturing the underlying dynamics between network activity and transaction costs.

The results of the Granger causality analysis reveal a unidirectional causal relationship from Gas Used to Gas Price, indicating that changes in network demand occur before and help predict movements in transaction fees. This finding demonstrates that the Ethereum fee market functions mainly as a demand-driven system in which congestion and competition for block space determine fee levels. Conversely, there is no significant evidence that variations in Gas Price influence Gas Used in the short term, suggesting that increases in transaction costs do not immediately reduce user activity. This asymmetric relationship shows that price adjustments serve more as a reactive response to network conditions rather than as a mechanism for controlling user demand.

The impulse response analysis reinforces these results by showing that shocks in Gas Used produce a temporary but noticeable increase in Gas Price that typically lasts for two to three days before returning to equilibrium. In contrast, shocks in Gas Price have only minor and short-lived effects on Gas Used. These findings imply that the Ethereum fee market efficiently incorporates current network conditions into transaction costs, reflecting a semi-efficient pricing mechanism in which transaction fees quickly adjust to reflect changes in network demand.

From a broader perspective, the dominance of network demand as a determinant of gas prices emphasizes the importance of congestion management and scalability solutions to maintain efficiency and user accessibility. As the Ethereum ecosystem continues to evolve, it becomes essential to design pricing mechanisms that balance network demand with transparent and predictable fee structures. Mechanisms such as adaptive block capacity and base fee adjustments could enhance the fairness and stability of the fee market. Overall, this study contributes to a deeper understanding of the economic dynamics of blockchain transactions and highlights the central role of network activity in determining transaction costs in decentralized digital systems.

Declarations

Author Contributions

Conceptualization: S.M., S.R., R.E., and P.K.; Methodology: S.R.; Software: S.M.; Validation: S.M., S.R., R.E., and P.K.; Formal Analysis: S.M., S.R., R.E., and P.K.; Investigation: S.M.; Resources: S.R.; Data Curation: S.R.; Writing Original Draft Preparation: S.M., S.R., R.E., and P.K.; Writing Review and Editing: S.R., S.M., R.E., and P.K.; Visualization: S.M.; All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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Informed Consent Statement

Not applicable.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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