



Article

An Event Study of the Ethereum Transition to Proof-of-Stake

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Abstract: On 15 September 2022, the Ethereum network adopted a proof-of-stake (PoS) consensus mechanism. We study the impact on the network and competing platforms in a two month event window around the Beacon chain merge. We find that the transition to PoS has reduced energy consumption by 99.98%. Miners have not transformed into validators, and total block reward income (in USD) has fallen by 97%, though transaction fees (in ETH) for Ether have increased nearly 10%. The Herfindahl index for the top 10 is 1009; the network is 19% less concentrated after the merge. Ethereum supply growth has been deflationary since the merge. The time between consecutive blocks is now steady at 12 s and transactions per day are up 7.0%. On Polygon, Matic fees rose but token fees fell. Polygon also slows, processing 3.3% fewer transactions per day. Solana's fees fall by \$0.0003, and transactions per day are down 48%. Stablecoin transfer volumes fall on Ethereum and Polygon, but rise on Solana.

Keywords: Ethereum; proof-of-stake; merge; cryptocurrency

JEL Classification: G12; G23



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1. Introduction

The Ethereum blockchain began operation on 30 July 2015. For more than seven years, the chain was secured by a proof-of-work (PoW) protocol. This entailed large clusters of specialized computers, known as mining networks, competing with one another to find a random number called the nonce. The first miner to show that the hash of the nonce was below the network's difficulty level would be allowed to add the new block to the chain. The miner would receive a block reward and collect gas fees for the transactions included in the block. As the network difficulty increased, the energy resources consumed by the miners grew ever larger.

On 13 August 2022, the electricity consumption of the network, using the methodology of de Vries [1], reached a peak, briefly consuming 93.975 Terrawatt hours (TWh) per year on an annualized basis. (McDonald [2] estimates a peak usage of 89 TwH.) An alternative, more conservative methodology of Krause and Tolaymat [3] estimates peak usage at 45% of de Vries [1]. For context, this annualized estimate exceeds the estimated yearly usage by the Philippines in 2018. (US Energy Information Administration [4]).

Vitalik Buterin, founder of the network, had advocated for a transition to proof-of-stake (PoS) as early as 2016. (Buterin [5]) This validation method requires stakers to verify new transactions. Instead of searching randomly for the nonce, stakers place their Ethereum holdings into a smart contract as collateral. If stakers fail to fulfill their validation responsibilities—accidentally or maliciously—they can be punished by losing their staked coins. Stakers for any given block are chosen via a pseudo-random algorithm known as RANDAO. (Randao.org [6]) Edgington [7] provides a more comprehensive discussion about RANDAO, and Park et al. [8] contains details on Ethereum's implementation of PoS.

Since PoS forgoes the energy-intensive problem solving characteristic of proof-of-work (Baniata and Kertesz [9] show that fog computing techniques can substantially reduce energy consumption in PoW distributed ledgers.), the Ethereum transition to PoS has cut the electricity usage of the network to 0.015 Terra Watts per hour, a 99.98% decrease, as seen in Figure 1.

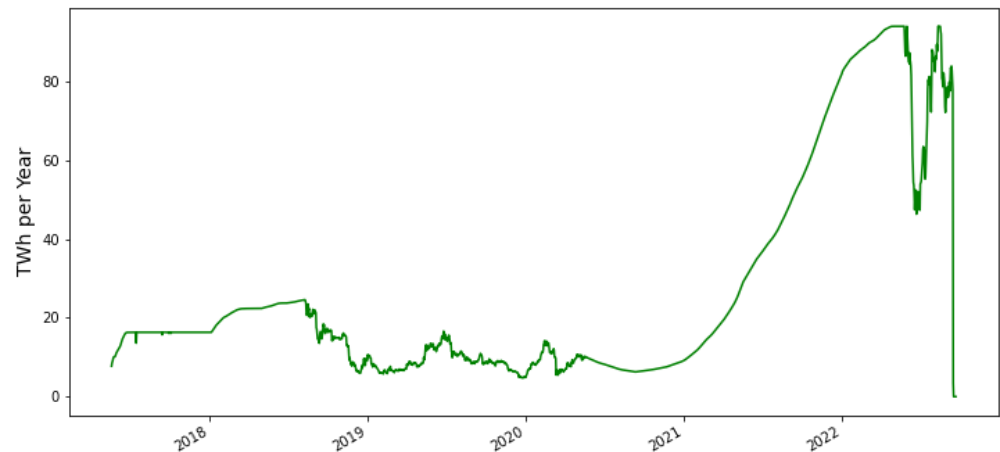


Figure 1. Electricity Consumption of the Ethereum Network. Data are collected by Digicomomist [10].

We describe the first six transition blocks in Table 1. The last block mined under PoW (<https://etherscan.io/block/15537393>. Accessed on 25 September 2022.) was 15537393 by F2 Pool Old at 6:42:42 AM GMT on 15 September 2022. It included only one ERC-721 (NFT) transaction. The first PoS block (The block was in slot 4700013, epoch 146875. A slot is a time period of 12 s in which a validator can propose a block. There are 32 slots in one epoch.) 15537394 was a normal sized block(<https://etherscan.io/block/15537393>. Accessed on 25 September 2022.) with 80 transactions, but it included a 45 Ether (ETH) priority fee (tip).

Table 1. Ethereum Blockchain Pre- and Post-Merge.

Index	Block_Datetime	Block_Number	Nonce	Miner	Difficulty	Gas_Used	Transaction_Count
1614	2022-09-15 06:42:35	15537391	12406352646189512271	0x829bd824b016326a401d083b33d092293333a830	11043900012338719	16,969,164	105
1615	2022-09-15 06:42:36	15537392	2534119505591571417	0xea674fdde714fd979de3edf0f56aa9716b898ec8	11049842297455506	29,990,952	61
1616	2022-09-15 06:42:42	15537393	7107786832965619657	0x829bd824b016326a401d083b33d092293333a830	11055787484078698	29,991,429	1
1617	2022-09-15 06:42:59	15537394	0	0xeeee27662c2b8eba3cd936a23f039f3189633e4c8	0	29,983,006	80
1618	2022-09-15 06:43:11	15537395	0	0x0b3b161b8abeb6b04cb95c3e6047f80c120a0292	0	29,982,083	29
1619	2022-09-15 06:43:23	15537396	0	0x388c818ca8b9251b393131c08a736a67ccb19297	0	29,980,461	170

Note: Nonce and difficulty, which were critical to proof-of-work, are now empty since they are not part of proof-of-stake. The miner column is now populated by the validator.

We will drop the transition day, 15 September, analyzing one month event windows preceding and following that date.

2. Data and Methods

This paper will examine the composition of the validator pool, block fees and rewards, and the network speed, on the Ethereum network. Our data sources are the Ethereum blockchain which we obtain from Kaggle. (<https://www.kaggle.com/datasets/bigquery/ethereum-blockchain>. Accessed on 25 October 2022.) Data from the pre-merge Beacon Chain is from Bitquery. (<https://explorer.bitquery.io/eth2>. Accessed on 25 October 2022.) We will also compare Ethereum to Polygon and Solana on fees, speed and transfer volumes. The Polygon data are from Quicknode, (<https://www.quicknode.com/docs/polygon>. Accessed on 25 October 2022.) and the Solana data are from its' command line interface. (<https://docs.solana.com/cli>. Accessed on 25 October 2022.) For Solana, we use 25,000 slot slices from each epoch in the month before and after the merge.

Our summary statistics are averages of fees, transactions per day, and transfer volumes. Since all are very large samples, we use *t*-tests to compare the means before and after the merge and report *p*-values from the normal distribution.

3. Descriptive Statistics for Ethereum

3.1. Validators

Prior to the merge, blocks were added by the miners. For the period 14 August to 14 September 2022, we computed the number of blocks and associated transactions that each miner completed. The top 10 miners, by blocks completed, are in Table 2. The Herfindahl index for the top ten is 1245. Ethermine has the largest market share at 28.6%.

Table 2. Most Active Miners Leading into the Merge.

Miner Address	Blocks Formed	No. Trans.	Miner Names
0xea674fdde714fd979de3edf0f56aa9716b898ec8	56,960	11,437,974	Ethermine
0x829bd824b016326a401d083b33d092293333a830	29,304	5,231,405	F2Pool
0x1ad91ee08f21be3de0ba2ba6918e714da6b45836	20,436	2,967,793	Hiveon
0x00192fb10df37c9fb26829eb2cc623cd1bf599e8	14,452	2,253,984	2Miners
0x7f101fe45e6649a6fb8f3f8b43ed03d353f2b90c	9859	1,397,143	Flexpool
0x2daa35962a6d43eb54c48367b33d0b379c930e5e	7004	1,086,420	Poolin 2
0x52bc44d5378309ee2abf1539bf71de1b7d7be3b5	5419	1,035,186	Nanopool
0x3ecef08d0e2dad803847e052249bb4f8bff2d5bb	4432	816,551	Mining Pool Hub
0xb7e390864a90b7b923c9f9310c6f98aaf43f707	4390	777,536	Unknown1
0xcd458d7f11023556cc9058f729831a038cb8df9c	3803	628,777	Poolin 4

Blocks are now secured by validators, participants in the Ethereum 2.0 consensus algorithm who have placed at least 32 ETH into the deposit contract (<https://etherscan.io/address/0x00000000219ab540356cBB839Cbe05303d7705Fa>. Accessed on 25 October 2022.) which we describe in Table 3. A committee of at least 128 validators, selected by RANDAO, are chosen to add a block for any given slot. One participant, called the block proposer, forms the block, a process that entails selecting and verifying a set of transactions has no failures or errors. The block then needs to be confirmed by the remaining validators, called attestors, who check and give their vote of confidence to the block. Finality is achieved at the checkpoint block, the first block in the next epoch, with support from 2/3 of the staked ETH. (<https://ethereum.org/en/developers/docs/consensus-mechanisms/pos/finality>. Accessed on 25 October 2022.)

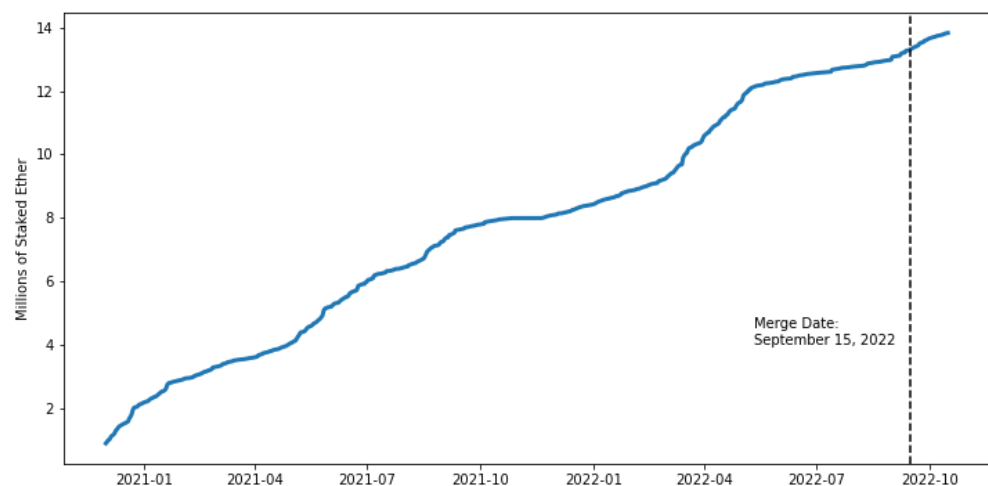
Table 3. Eth 2.0 Deposit Contract.

Smart Contract Address:	0x00000000219ab540356cbb839cbe05303d7705fa
Name:	Beacon Deposit Contract
Creator:	0xb20a608c624Ca5003905aA834De7156C68b2E1d0
Deployed:	2020-10-14
Block:	11,052,984
Transaction hash:	0xe75fb554e433e03763a1560646ee22dcb74e5274b34c5ad644e7c0f619a7e1d0
Balance on 2022-08-14:	13,291,512 ETH
Balance on 2022-10-16:	13,836,087 ETH

The randomness of selection means that validators must have an active system nearly 24/7; they can have some or all of their stake burned (A term used to describe ETH that is cut loose from the network and is thus inaccessible to any user.) and be removed slashed) from the set of validators, for failing to complete an assigned task. As of 1 November 2022, 217 validators have been slashed, (<https://beaconcha.in/validators/slashings>. Accessed on 1 November 2022.) 24 since the merge.

In order to incentivize ETH holders to stake in the network, validators are compensated in two ways. The block proposer claims the gas fees, net of burning. Validators also receive rewards for attesting to and finalizing blocks. (<https://ethereum.org/en/developers/docs/consensus-mechanisms/pos/rewards-and-penalties/>. Accessed on 7 October 2022.) This reward is a function of the total network stake, with the return inversely proportional to the square root of the number of validators.

We plot the cumulative deposits into the staking contract in Figure 2. Deposits to the Beacon Chain staking contract began in November 2020. Heading into the merge the total supply in the deposit contract exceeded 13.2 million Ether.

**Figure 2.** Cumulative Stake in the Ether Deposit Contract.

Pintail [11] provides estimates of the returns to staking Ethereum on the Beacon Chain which draws on the Ethereum 2.0 annotated specification of Edgington [7]. With 401,084 validators on the merge day, this model estimates a return of 1.49 ETH over the year, an annualized yield of 4.64%. If the number of validators were to double, the return would fall to 1.05 ETH or just 3.28%.

We computed the number of blocks and transactions that each validator proposed from 16 September to 16 October 2022. The top 10 validators by blocks completed can be seen in Table 4. The Herfindahl index for the top 10 is 1009; the network is 19% less concentrated after the merge.

Table 4. Most Active Block Proposers Since the Merge.

Fee Receiver Address	Blocks Vldtd.	No. Trans.	Validator Name
0xdafea492d9c6733ae3d56b7ed1adb60692c98bc5	45,688	8,809,237	Flashbots
0x388c818ca8b9251b393131c08a736a67ccb19297	36,753	5,536,598	Lido Execution Layer
0x4675c7e5baafbfbca748158becba61ef3b0a263	32,827	4,265,292	Coinbase
0xf2f5c73fa04406b1995e397b55c24ab1f3ea726c	10,891	2,176,154	bloXroute: Max Profit
0xebec795c9c8bbd61ffc14a6662944748f299cacf	10,540	1,383,861	Contract1
0xe688b84b23f322a994a53dbf8e15fa82cdb71127	9197	1,221,402	Address1
0x690b9a9e9aa1c9db991c7721a92d351db4fac990	7903	1,694,011	builder0x69
0x199d5ed7f45f4ee35960cf22eade2076e95b253f	5045	1,057,766	bloXroute: Regulated
0x6d2e03b7effeae98bd302a9f836d0d6ab0002766	4793	587,538	Address2
0xb646d87963da1fb9d192ddba775f24f33e857128	3577	766,706	MEV Builder

Moreover, there is no overlap between the pre-merge miners and the post-merge validators. Miners' comparative advantage is their computing power, but this does not give a meaningful leg-up for PoS validation. Some miners have migrated to other networks that are still using PoW. In fact, the reward for mining an Ethereum Classic or RVN blocks, which still use PoW, dropped roughly 84% and 97%, respectively, within a 24-h period around the merge. (<https://www.coindesk.com/business/2022/09/15/ethereum-miners-are-quickly-dying-less-than-24-hours-after-the-merge/>. Accessed on 1 October 2022.)

The dominant validators are Flashbots, a research collective designed to mitigate the problem of maximum extractable value (MEV), a measure of the profit a network participant can make through “their ability to arbitrarily include, exclude, or re-order transactions from the blocks they produce.” (<https://www.flashbots.net/>. Accessed on 25 November 2022.) In other words, since there is no formal regulation around the order of transactions in a block, or which transactions are included in a block, validators could choose to prioritize certain types of transactions, giving those parties systemic advantages when trading. (Jensen [12] points out that the opportunity space is much larger if the manipulable set spans multiple blocks. They estimate that more than 20% of the blocks since the merge share single builder entries.)

In the proof of stake regime, Flashbots has released MEV-Boost, an open-source algorithm which sells blockspace to an open market of builders. On 15 September 2022, 17 epochs after the merge, MEV-Boost was activated. BioXroute (<https://docs.bloxroute.com/apis/mev-solution/mev-relay-for-validators>. Accessed on 25 November 2022.) and MEV Builder utilize MEV-Boost. (builder 0x69 utilizes two relays, Flashbots and Relayooor, <https://medium.com/@builder0x69>. Accessed on 25 November 2022.) The four Flashbots addresses have validated 46.6% of the blocks in the month since the merge.

While it may not be computationally intensive, validating requires a large capital commitment, a great deal of technical knowledge, and a round-the-clock connection to the network. There are, however, on- and off-chain methods for retail investors, who would otherwise be locked out due to these stringent demands, to become validators. Validation pools, such as Lido, have been a popular on-chain method of staking—in fact, as seen in Table 4, Lido is the dominant staking pool in the market. Users pool their resources into Lido by purchasing its staking token, stETH. (The hash on the Ethereum Mainnet is 0xae7ab96520de3a18e5e111b5eaab095312d7fe84.) Lido then invests the pooled assets into the staking contract, and distributes the rewards amongst the investors. The cumulative amount staked in Lido can be seen in Figure 3. (Heimbach et al. [13] note that Lido can also be staked, and that nearly 20% was locked into DeFi lending protocols during the merge, creating a potential for mass liquidations.)

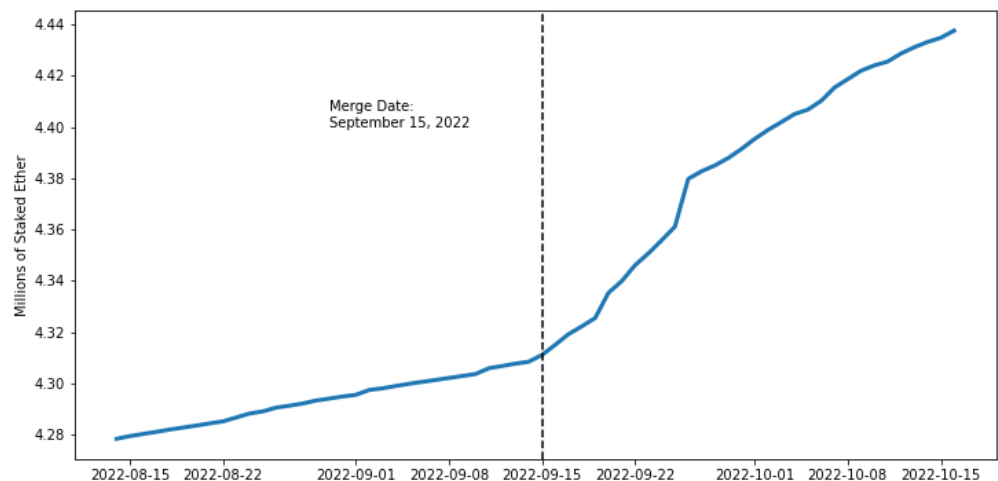


Figure 3. Cumulative Supply in the Lido Staking Token.

There are also off-chain solutions for retail staking, namely through centralized exchanges. As seen on Table 4, Coinbase is the second largest staker in part due to a service that mirrors Lido's on-chain pooling; Coinbase users can offer any amount of ETH to be pooled and staked in the deposit contract. Other centralized exchanges, like Binance, offer similar services; Kraken offered such a service for the duration of this sample, but have since shut down user staking pools. Since daily issuance of new ETH to the validators is a function of the total amount of ETH staked, tracking the dominant validators may be important insofar as understanding the growth in ETH supply.

Validators can't withdraw ETH from the staking contract until the Shanghai upgrade. At the time of the Merge, it was anticipated that the upgrade would take six to eighteen months, and it is now on pace for the lower end of that range, March 2023. (<https://www.bloomberg.com/news/articles/2023-01-27/crypto-s-hottest-trade-risks-spurring-another-leverage-bubble#xj4y7vzkg>. Accessed on 30 January 2023.)

3.2. Block Income and Creation Speed

Historically, income for miners has come from two sources: block rewards for completing a new block on the chain and transaction fees from on-chain transfers. Since August 2021, after the EIP-1559 upgrade, (<https://notes.ethereum.org/@vbuterin/eip-1559-faq>. Accessed on 30 September 2022.) base fees from transfers have been burned. A miner's block income, prior to the merge, consisted of these three parts shown in Equation (1):

$$\text{Block Income} = \text{Block Reward} + \text{Transaction Fees} - \text{Burnt Gas} \quad (1)$$

Block reward is the number of new ETH minted and given to the party responsible for successfully adding a block to the chain; transaction fees, include the gas, both base and priority fees, from the transactions in the block; burnt gas for each transaction is the base fee in ETH set by the network protocol.

Since the St. Petersburg upgrade in 2019, miners received two ETH for each block they completed. However, the transition to PoS removed this reward altogether. Miner and validators' total block income before and after the event is plotted in Figure 4.

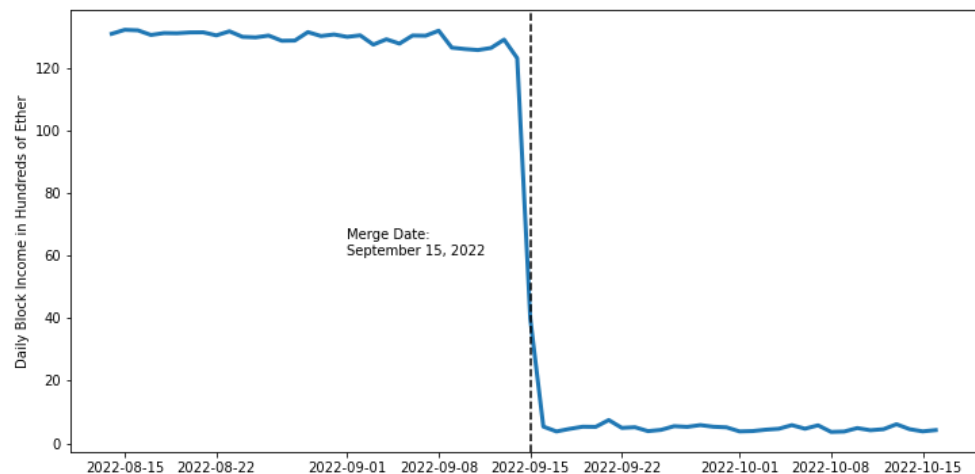


Figure 4. Total Block Income in Ether.

Table 5 decomposes the decline in block income. There is a slight, statistically insignificant rise in transaction fees for transfers, but it is largely offset by a higher burn rate. The loss of a block completion bonus is the main drag on block income. Validators' total block income is now only 3% of what miners used to earn.

Table 5. Daily Block Income Before and After the Merge.

Measure	Pre-	Post-	<i>t</i> -Stat	<i>p</i> -Val
Block Tx Fees (Ether)	1675	1889	1.41	0.1643
Block Burn Fees (Ether)	1207	1413	1.41	0.1648
Total Block Income (Ether)	12,462	479	−300.95	0.0000
Total Block Income (USD)	\$20,732,030	\$638,820	−61.52	0.0000

The removal of the block completion reward has also greatly slowed the minting of new ETH. Since the St. Petersburg Upgrade, (The updates went live at block 7,280,000 on 28 February 2019: <https://cointelegraph.com/news/etheriums-constantinople-st-petersburg-upgrades-have-been-activated>. Accessed on 30 September 2022.) two new ETH were minted as a reward for each completed block; this served as the main driver of ETH supply expansion. Combined with a smaller issuance for ommer blocks (<https://ethereum.org/en/glossary/ommer>. Accessed on 30 September 2022.) and validators on the Beacon Chain, (<https://ethereum.org/en/upgrades/beacon-chain/>. Accessed on 30 September 2022.) there was about 5.5 million new ETH minted annually. (<https://ethereum.org/en/upgrades/merge/issuance/>. Accessed on 30 September 2022.) Since the merge, the two ETH per transaction reward on the execution layer (PoW) are no longer being produced. There is now roughly 1600 new ETH minted each day, which is distributed to the validators in the network. The burn rate can, in principal, exceed the issuance rate, resulting in blocks that deflate total ETH supply. Finally, ETH continues to be staked, removing it from the circulating supply. These factors explain why, as we show in Figure 5, that ethereum supply has been deflationary since the merge.

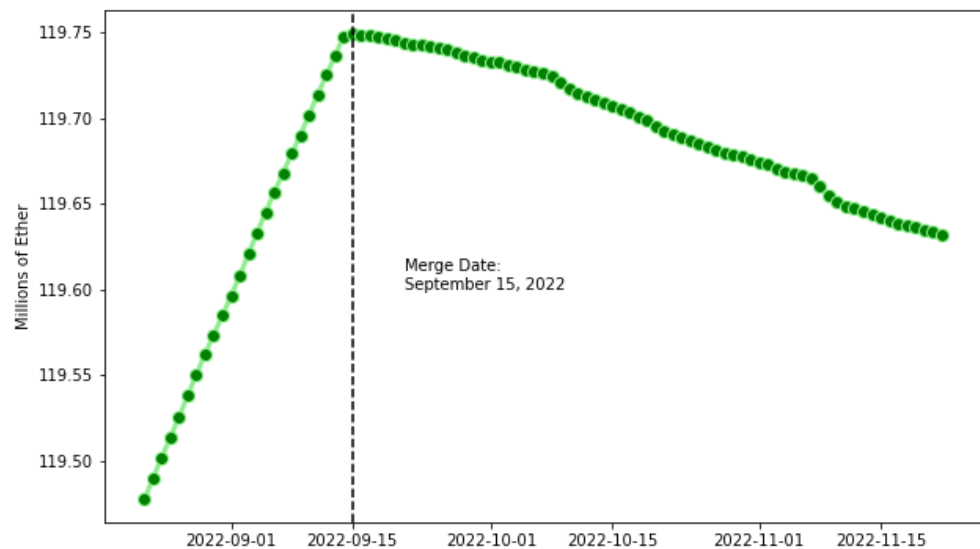


Figure 5. Ethereum Supply. The data are from Coinmetrics.

3.3. Transaction Fees: Ether Transactions

As Donmez and Karaivanov [14] note, miners generally received only the base fee of 21,000 units of gas for ETH transfers between two wallets. The dollar price of the transaction can vary quite widely because: (1) the ETH price of a unit of gas deviates with network congestion and (2) the dollar price of ETH, until recently, was increasing steadily.

The median fee in Figure 6 peaked at over \$28 on 11 May 2021. Following a temporary dip, prices remained over \$10 through November 2021, but have fallen since. Going into the merge, the median price was \$0.502.

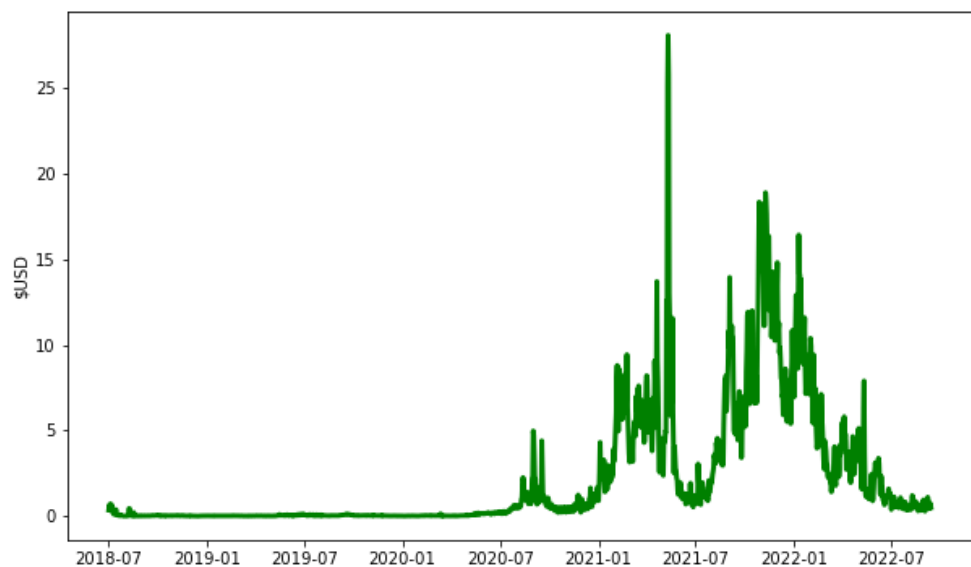


Figure 6. Median Fees for Ether Transactions in U.S. Dollars (\$USD).

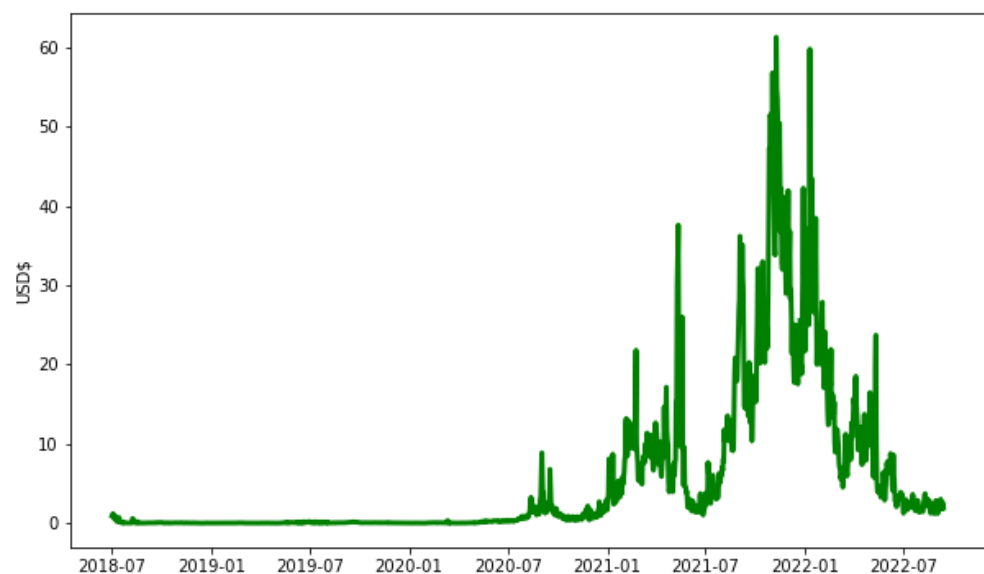
As seen in Table 6, gas price and gas used for ETH transactions have seen statistically significant increases since the merge. That said, given the strong decline in ETH/USD during the event window, there has actually been a slight decrease in the dollar cost of fees, but this change is not statistically significant.

Table 6. Ether Transaction Fees Before and After the Merge.

Measure	Pre-	Post-	<i>t</i> -Stat	<i>p</i> -Val
Gas Price (Gwei)	17.3279	22.6959	2.76	0.0070
Gas Used $\cdot 10^4$	6.8570	7.3321	3.85	0.0002
Fees in Ether $\cdot 10^{-3}$	1.1719	1.2872	3.60	0.0005
Fees in USD	\$1.9453	\$1.7031	−1.62	0.0906

3.4. Transaction Fees: Ethereum Tokens

By construction, ERC-20 tokens live in smart contracts, which introduce more complexity to parse. Thus, fees have typically been higher for token transfers. As seen in Figure 7, token fees peaked at over \$61 on 9 November 2021 and medians were still above \$20 through May 2021.

**Figure 7.** Median Fees for Ether Token Transactions.

We analyze the impact of the merge on ERC-20 transactions in Table 7.

Table 7. ERC-20 Token Transaction Fees Pre- and Post-Merge.

Measure	Pre-	Post-	<i>t</i> -Stat	<i>p</i> -Val
Gas Price (Gwei)	18.8273	18.3042	−0.35	0.7246
Gas Used $\cdot 10^5$	1.1104	1.1443	1.86	0.0670
Fees in Ether $\cdot 10^{-3}$	1.9458	1.9706	0.14	0.8868
Fees in USD	\$3.2387	\$2.6106	−2.56	0.0131

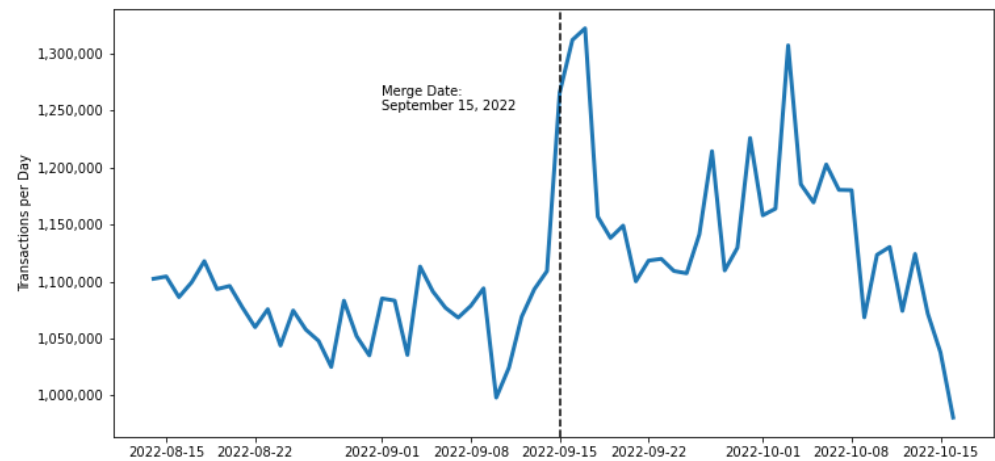
Gas prices are down, gas used on token transactions is up, resulting in a small increase in fees in Ether terms. The decline in ETH/USD leads to the only statistically significant change, a decline in the dollar cost of transfer fees of \$0.62.

3.5. Block Creation Speed

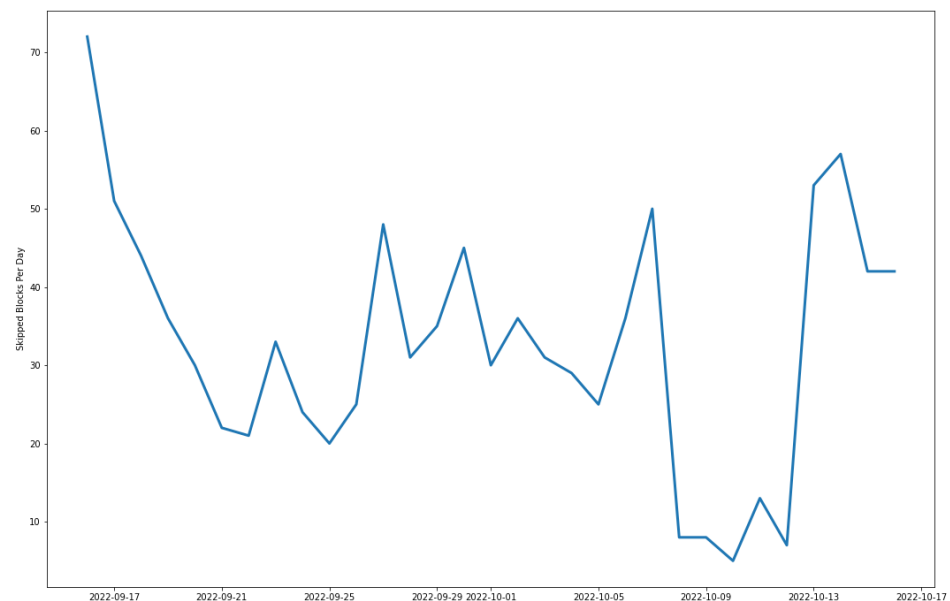
Prior to the merge, blocks were added when a miner group “won the race” to find the nonce. As a result, block creation speed would vary. Except on the rare occasions that a block is skipped, validators produce a new block every twelve seconds. Given this faster speed, as seen in Table 8 and Figure 8, transactions per day are up by 75,000 on average.

Table 8. Daily Average Transactions Before and After the Merge.

Measure	Pre-	Post-	<i>t</i> -Stat	<i>p</i> -Val
Transactions per day	1,073,508	1,148,750	5.29	0.0

**Figure 8.** Transactions per Day.

In fact, as seen in Figure 9, there were only 32.5 blocks per day, on average, that were not created exactly 12 s after the preceding block. All these blocks were created 24 s afterwards. This consistency occurs by design: blocks are now added by chosen validators into specific slots, each 12 s apart. The only reason why slots are “skipped”, is due to a failed block creation. JumpCrypto [15] notes that blocks can fail because of honest errors on the part of validators, either because of network failures or storage issues. The more serious concern, they emphasize, is sequential block failure, likely from malicious attacks or poor client implementations among a large number of validators. They report only two delays reaching one minute in over 900,000 blocks since the merge.

**Figure 9.** Skipped Blocks per Day.

Increased and more stable block formation speed could allow for more on-chain activity. Pavloff et al. [16] suggests, however, that there may be limits to how quickly PoS networks can achieve consensus.

4. Descriptive Statistics for Other Networks

4.1. Polygon

Polygon is a layer 2 scaling solution on the Ethereum network. While it exists alongside the original chain, it creates a separate chain that is faster, maintaining higher transactions per second, and lowers fees per transaction.

We analyze Matic only transactions, the utility token on Polygon, and ERC-20 tokens in Table 9.

Table 9. Transaction Fees on Polygon Before and After the Merge.

Measure	Pre-	Post-	<i>t</i> -Stat	<i>p</i> -Val
Matic Fees in USD	\$0.0232	\$0.0242	0.28	0.78
Token Fees in USD	\$0.1333	\$0.1244	−0.39	0.70

The merge's cross network impact lowers Polygon's Matic fees and raises token fees on the Mainnet. Neither change is statistically significant.

We will next analyze the network speed around the merge, as measured in Table 10.

Table 10. Polygon Daily Network Volume.

Measure	Pre-	Post-	<i>t</i> -Stat	<i>p</i> -Val
Transactions per day	2,821,632	2,729,498	−1.49	0.14

The number of transactions per day fell by about 98,000 (3%), but this change is not statistically significant.

4.2. Solana

Solana is an open source, permissionless Layer 1 blockchain that relies on proof-of-history. (<https://docs.solana.com/introduction>. Accessed on 13 March 2023.) Through applications like Wormhole, (<https://solana.com/news/wormhole---solana-ethereum-bridge>. Accessed on 13 March 2023.) ETH and ERC-20 tokens are readily bridged to Solana. We make the comparison here to Solana because Ethereum's planned move to sharding has been to match the transaction capabilities and lower fees of Solana. (DigitalTrend [17]).

In Table 11, we report a small reduction in fees, significant at the 1% level.

Table 11. Token Transaction Fees on Solana Before and After the Merge.

Measure	Pre-	Post-	<i>t</i> -Stat	<i>p</i> -Val
Token Fees in USD	\$0.0011	\$0.0008	−3.32	0.001

As for speed, Table 12 shows that the network, prior to the merge, processes almost 40 times as many transactions as Ethereum and 15 times as many as Polygon.

Table 12. Solana Daily Network Volume.

Measure	Pre-	Post-	<i>t</i> -Stat	<i>p</i> -Val
Transactions per day	42,400,730	22,127,360	−6.89	0.000

Solana slows by 48% after the merge. This appears to be related to issues to network outages on Solana. (Coin Telegraph, 13 August 2022, <https://cointelegraph.com/news/ominous-solana-technicals-hint-at-sol-price-crashing-35-by-september>. Accessed on 15 October 2022.) Despite this, Solana remains 19 times faster than Ethereum and eight times faster than Polygon.

5. Transfer Volume Results

We analyze transfer volume on Ethereum, Polygon, and Solana in two major stablecoins (Stablecoins are unique from other assets in that their value is pegged to another asset, typically fiat currency, namely USD. For more information on Stablecoins, see Mizrach [18]), USD Coin (USDC) and Tether (USDT). We choose these tokens because they are issued natively on the three platforms, (USD Coin: <https://www.circle.com/en/usdc-multichain/>; Tether: <https://tether.to/en/transparency/>. Both accessed 15 October 2022.) are traded actively, and have a stable value. Ethereum dominates the other two platforms prior to the merge with 89% of the transfer volume in USDC and 76% of the volume in USDT, as seen in Tables 13 and 14.

Table 13. USDC Average Daily Transfer Volume in Billions (ADVbn.).

USD Coin ADV bn.	Pre	Post	<i>t</i> -Stat	<i>p</i> -Val
Ethereum	13.81	11.02	−1.75	0.09
Polygon	0.63	0.47	−1.88	0.07
Solana	1.00	1.53	1.65	0.12

Solana's USDC volume rises more than 500 million per day, and it regains market share after the merge, rising from 6% to 11%.

Table 14. USDT Average Daily Transfer Volume in Billions (ADVbn.).

Tether ADV bn.	Pre	Post	<i>t</i> -Stat	<i>p</i> -Val
Ethereum	2.97	2.75	−0.97	0.34
Polygon	0.16	0.14	−1.21	0.23
Solana	0.80	1.08	1.52	0.14

Solana's USDT volume average is again the only to rise after the merge. The transfer volume increase of 280 million per day raises its' market share to 27% after the merge.

6. Discussion

The main social benefit from the merge has been the massive decrease in the amount of energy used by the network; continuation of proof-of-work was likely unsustainable.

Surprisingly though, transaction fees in Ether for both Ether-only and ERC-20 transactions have risen since the merge. However, as per Table 15, declining prices for the utility tokens lower network fees in USD, except for Matic transactions on Polygon.

Table 15. Fees in USD on Ethereum, Polygon and Solana.

	Pre-	Post-
Ether Transactions	\$1.9453	\$1.7031
Ethereum Tokens	\$3.2387	\$2.6106
Polygon Matic Transactions	\$0.0232	\$0.0242
Polygon Tokens	\$0.1333	\$0.1244
Solana Tokens	\$0.0011	\$0.0008

As seen in Table 16, network activity rose slightly on Ethereum and fell slightly on Polygon. Solana has slowed by almost 50% which may be attributable to major network outages on 30 September and 1 October 2022. (<https://status.solana.com/uptime?page=2>. Accessed on 30 October 2022.)

Table 16. Daily Transaction Volume on Ethereum, Polygon and Solana.

Transactions per Day	Pre-	Post-
Ethereum	1,073,508	1,148,750
Polygon	2,821,632	2,729,498
Solana	42,400,730	22,127,360

7. Conclusions

The transition from proof-of-work to proof-of-stake has also reshaped the entire Ethereum landscape. The composition of block creators has entirely changed; there is not one miner from the PoW regime that is now proposing or attesting to blocks as a validator under the PoS regime. While gas transaction fees for network participants have grown since the merge, so has the amount of ETH burned. Block rewards were many times larger than the daily variable sum, distributed to the validators. Because of the loss of block rewards, increased burn rates, and more staked Ether, the total circulating supply is now deflationary.

There are several questions for future research. What will be the long run return to staking? This will depend upon what happens after the Shanghai upgrade enables stakers to withdraw their ETH. (<https://www.bloomberg.com/news/articles/2022-09-14/-illiquidity-risk-is-a-side-effect-of-ethereum-crypto-upgrade>. Accessed on 15 September 2022.) A second factor is the frequency of slashes in the validator pool. 216 validators have already been slashed for improper actions as validators. (<https://www.blocknative.com/blog/an-ethereum-stakers-guide-to-slashing-other-penalties>. Accessed on 15 January 2023).

Will decentralized staking systems like Lido dominate centralized exchanges like Coinbase? Will Ethereum gas fees eventually fall given the reduction in energy needed to secure the network? Will other proof-of-work networks look to transition to proof-of-stake or other less energy intensive models of block formation? Finally, will sharding, which effectively makes individual nodes into their separate blockchains, (<https://ethereum.org/en/upgrades/sharding/>. It is projected to arrive sometime in 2023. Accessed on 15 September 2022.) enable Ethereum to achieve latencies (Kertesz and Baniata [19] demonstrate that there is a tradeoff between validators' computational abilities and network latencies.) and fees similar to Solana?

Lastly, major policy questions are still unresolved in the digital asset space. Specifically, Chairman Gensler of the SEC has suggested that staking may qualify certain blockchains as securities, as per the Howey Test, (Paul Kiernan and Vicky Ge Huang, Ether's New 'Staking' Model Could Draw SEC Attention. *Wall Street Journal*, 16 September 2022. Accessed on 15 October 2022.) though Ethereum is currently classified as a commodity by the Commodity Futures Trading Commission (CFTC). (The CFTC asserts this in their filing against Sam Bankman-Fried: A digital asset is anything that can be stored and transmitted electronically and has associated ownership or use rights. Digital assets ... function as mediums of exchange, units of account, and/or stores of value. Certain digital assets are "commodities", including...ether (ETH)... as defined under Section 1a(9) of the Act, 7 U.S.C. § 1a(9).) Kraken has recently discontinued its Staking-As-A-Service program as part of a \$30 million settlement with the SEC. (<https://www.sec.gov/news/press-release/2023-25>. Accessed on 15 February 2023.) Gensler has made it clear (<https://www.sec.gov/news/statement/gensler-statement-custody-021523>. Accessed on 15 February 2023.) that centralized exchanges are not "qualified custodians", so this action against Kraken could potentially be applied more broadly. If the custodial rules were also applied to on-chain assets like Lido, nearly 50% of staked Ether could be impacted.

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