Review of Mining Emissions and Risks of the Halving

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[*] While Jesse is a lawyer, nothing in this paper should be construed as legal advice. The legal risks of implementing any of the solutions discussed in this report have not been analyzed.

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1 Background

1.1 Factual Background

In January of 2021, the Stacks 2.0 blockchain launched. With its launch, the schedule for the block rewards awarded to miners who mine the Stacks blockchain was set in its code. This code sets the number of Stacks tokens that are awarded to a miner when a miner wins a block (this amount is often referred to as the "coinbase").

This mining reward schedule set forth that, for the first approximately 4 years of the blockchain, the coinbase would be 1000 Stacks tokens per block.[2] Then that would be cut in half to 500 Stacks tokens per block for the following 4 years. And then that would be cut in half to 250 Stacks tokens per block for all years following that.

Stacks blocks are mined, and therefore the Stacks coinbase is awarded, approximately every 10 minutes, at the same time and rate as the mining of Bitcoin blocks.

The initial halving, cutting the Stacks coinbase reward from 1000 Stacks per block to 500 Stacks per block, is currently scheduled to happen in January 2025.

There is some concern amongst the Stacks community that this anticipated halving will negatively impact the Stacks network, which remains in its relative infancy. With over two years of mining data, we can now better understand the economic realities of Stacks mining, and we can use this data to understand some potential consequences of the anticipated halving proceeding as had been planned.

1.2 Key Questions

We believe the overarching question is whether the risks to the Stacks blockchain of the halving proceeding as planned are greater than the risks and consequences of the halving being delayed or altered in some way?

To delve into this question, we need to first examine the purpose of the mining incentive. The Stacks mining coinbase provides incentive for three different purposes for the Stacks blockchain:

- Provides an incentive to a decentralized group of miners to participate in mining.
- Creates a cost, or disincentive, to mine the network dishonestly.
- Provides an incentive to Stackers to participate in Stacking.

It follows from the above that decreasing the coinbase via the halving may reduce the incentives for each of these areas. We therefore think there are few key questions that flow directly from the above. How might the halving of the Stacks block reward affect:

- Miner centralization?
- The security of the Stacks blockchain?

[2] For the first 10,000 blocks of the Stacks 2.0 blockchain there was an additional mining bonus of approximately 1,446 Stacks per block, meaning the coinbase for those first 10,000 blocks was approximately 2,446 Stacks per block.

- Stacking participation?

Understanding each of these areas will allow us to develop some intuition around the risks of the halving moving ahead.

Miner Centralization: We believe it's important for the Stacks blockchain to have a robust and competitive mining process. If the rewards are cut in half, it may result in fewer miners participating in the mining process, and less mining competition. The number of miners who currently mine on the Stacks blockchain is already a concern for many. This analysis will look at historical mining data, to examine the potential impact on the degree of centralization of miners if the coinbase rewards are to be halved.

Network Security: Coinbase rewards can, to some extent, be thought of as a security budget for the network. If the cost of winning a block becomes less expensive, it may be less expensive for an attacker to manipulate the Stacks blockchain in various ways. We will examine potential risks and issues that may arise because of the planned coinbase "security budget" being slashed.

Stacking Participation: We might expect that, with a decrease in mining rewards, miners will commit less value to the mining process for each block, and therefore Stackers who participate in Stacking will receive fewer Stacking rewards. We might then expect Stacking participation to decrease in turn. This, in itself may not be ideal, but also may have a second-order consequence. The planned design for sBTC requires that Stackers serve as signers for the Bitcoin locked up for the sBTC protocol. Key to aligning incentives for sBTC signers will be ensuring that the value of the Bitcoin locked for sBTC reserves remains some percent (less than 100%) of the value locked in Stacking. If the coinbase rewards decrease by half, and the volume of Stacking participation decreases in turn, it may result in sBTC as a system being unable to support as much value as would be ideal.

We also will need to examine the consequences and risks of delaying the halving. A few key considerations we will examine are:

- Will there be positive price-effects to the halving proceeding as planned and would such an effect mitigate, or should otherwise be prioritized over, other concerns?
- Will adjusting the emissions schedule result in a loss in confidence that the future emissions schedule won't be further adjusted?
- Will adjusting the emissions schedule result in a loss in confidence more broadly regarding the stability of the Stacks blockchain?

We'll discuss the above issues in the sections below.

2 Analysis

2.1 Conceptual Analysis of Mining

Before diving into historical mining data, it's important that we have a conceptual understanding of Proof-of-Transfer (PoX) mining and, based on that conceptual understanding, have an expectation of how miners might behave.

We'll provide a quick, high-level background for PoX mining. Further details can be found through resources available on the Stacks Foundation website.

For PoX mining, there are two primary actors. First, there are miners who contribute Bitcoin to compete for, and ultimately, mine Stacks blocks. And second, there are Stackers, who hold and lockup Stacks tokens. Miners send their Bitcoin to Stackers, and the amount they send relative to the total amount sent for a given block is proportional to the miner's chances for winning that block.

Miners have two primary expenses. The first is the amount of Bitcoin they send to Stackers for each block that they mine. And the second is the amount of Bitcoin transaction fees they use to send those transactions. The amount of Bitcoin a miner sends to Stackers is proportional to the miner's probability of winning a block.[3] The amount of Bitcoin transactions fees that a miner spends does not affect their probability of winning a Stacks block, except that if they don't spend enough in transaction fees, their Bitcoin transaction may not be included in a Bitcoin block, and therefore their Stacks mining commitment would not be recognized.

When a Stacks miner wins a Stacks block, they are awarded the Stacks coinbase (currently 1000 Stacks per block) plus any Stacks transaction fees for Stacks transactions they've included in that block. Currently, transaction fees for Stacks transactions are negligible as compared to the value of the Stacks coinbase. For the analysis in this paper, we've omitted the value of the transaction fees, and assume they will remain negligible for the foreseeable future as an incentive for miner rewards.

Assuming a miner is profit-driven and rational, we should expect that their profit would generally need to be greater than zero in the long run. The total profit for all miners for a given block would simply be the value of the coinbase minus the sum of the total commitments of miners, C, and the total Bitcoin fees paid by miners, F:

$$Profit = Coinbase - (C + F)$$

Let's call the sum of total miner commitments and total miner Bitcoin fees "mining costs." We can see that if mining costs exceed the value of the coinbase, then miners' profits would be negative, and vice versa.

Stacks mining can be thought of as a highly competitive market. There are very few barriers to entry and exit. Anyone, assuming they have sufficient capital and a baseline level of technical expertise, can begin mining on the Stacks blockchain. One does not need to receive approval from anyone, buy hardware or equipment, or wait any sort of meaningful time to start mining.

In addition, Stacks mining is highly transparent. Any non-miner (assuming sufficient technical ability) can see the current profit that is being made by miners. This allows for non-miners to be able to make an informed decision to become a miner at any time.

With all these conditions, we might expect that the profit for miners would tend to zero. With little friction and high visibility, we would expect that if there is enough excess profit,

[3] There is some further nuance here. The Stacks blockchain calculates a miner's commitment in each block as the lesser of the miner's commitment for that block (i.e., the amount of Bitcoin the miner sends for that block) or the median of the miner's commitments over the last five blocks.

another miner will easily swoop in and earn it. If there are losses, some miners will simply drop away.

The above equation, however, is missing opportunity cost. In the case of miners, this could be, for instance, their cost of capital and time in maintaining and monitoring their mining system. And so we'd ultimately expect that mining costs would tend towards some high percent, though less than 100%, of the value of the coinbase. This small profit will leave some value available to cover the opportunity costs for miners.

Given the design of Stacks mining, there is a theoretical limit to the number of miners who can mine without losing money. The absolute maximum number of miners the Stacks blockchain can support for each block is the value of the coinbase divided by the fees for a Bitcoin transaction. As such, if Bitcoin fees otherwise remain constant, the lower the value of the coinbase, the fewer miners that can mine the Stacks blockchain.

We expect the real number of miners to be far fewer than the theoretical limit. However, we believe the number of miners would continue to be a function of the value of the coinbase. As the value of the coinbase in excess of the fees decreases, the fewer number of miners will participate. Conceptually, the smaller the pie, the fewer number of people will consider it worthwhile to compete for a piece.

With these conceptual frameworks in mind, we can now examine the historical mining data to see how miners have generally behaved since the start of Stacks blockchain 2.0.

2.2 Historical Mining Analysis

2.2.1 Methodology

We received and analyzed mining data from the start of the Stacks 2.0 blockchain (when the current version of mining for the Stacks blockchain was introduced) on January 14, 2021, through to data encompassing Bitcoin block 784,957, which was mined on April 11, 2023.

To get a clear picture of the data for the questions we wanted to answer, we made some adjustments to the data set. First, we sought to eliminate "flash blocks." Flash blocks are Bitcoin blocks that are mined very quickly in succession, and often do not allow time for Stacks miners to have their Stacks mining commitments included in the Bitcoin block that quickly follows.

To eliminate flash blocks, we removed blocks where *both* the number of commitments decreased by two or more from the previous block, *and* where the number of commitments increased by two or more for the next block. In other words, we removed blocks where there was a one-block dip in the number of commitments by two or more. Out of the approximately 110,000 blocks that we analyzed, this removed approximately 6,700, or 6%.

Second, we eliminated blocks where it was clear that a Bitcoin miner was running an MEV strategy. That is, the Bitcoin miner was excluding Stacks miners' commitments from the Bitcoin block they were mining. This strategy allows for the Bitcoin miner to commit a de

minimis amount of Bitcoin to win the Stacks block, given there are no other competing miners for that Stacks block.[4]

MEV blocks are easily identified and excluded because they have very low amount of Bitcoin commitment and Bitcoin fees, and they only started relatively recently. While many of these blocks were excluded as part of the flash block filter, there were a few hundred additional blocks that we removed.

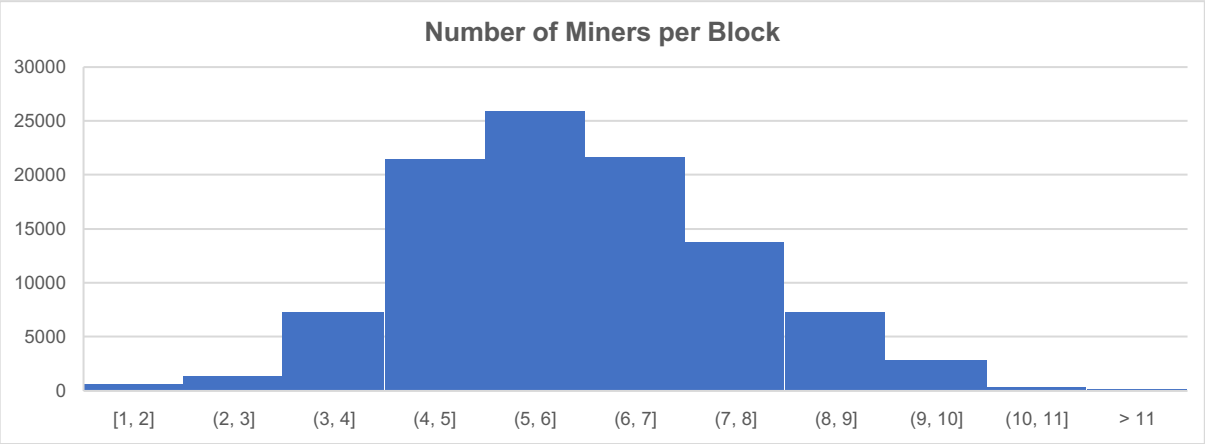
2.2.2 Mining Participation and Statistics

With this cleaned data set, we sought to understand various historical attributes of Stacks mining. We wanted to develop an understanding of:

- The number of miners that mined per block;
- The Bitcoin fees that miners paid per block;
- The Bitcoin commitment amounts miners contributed in relation to coinbase value; and
- The number of miners per block in relation to the coinbase value and Bitcoin fees.

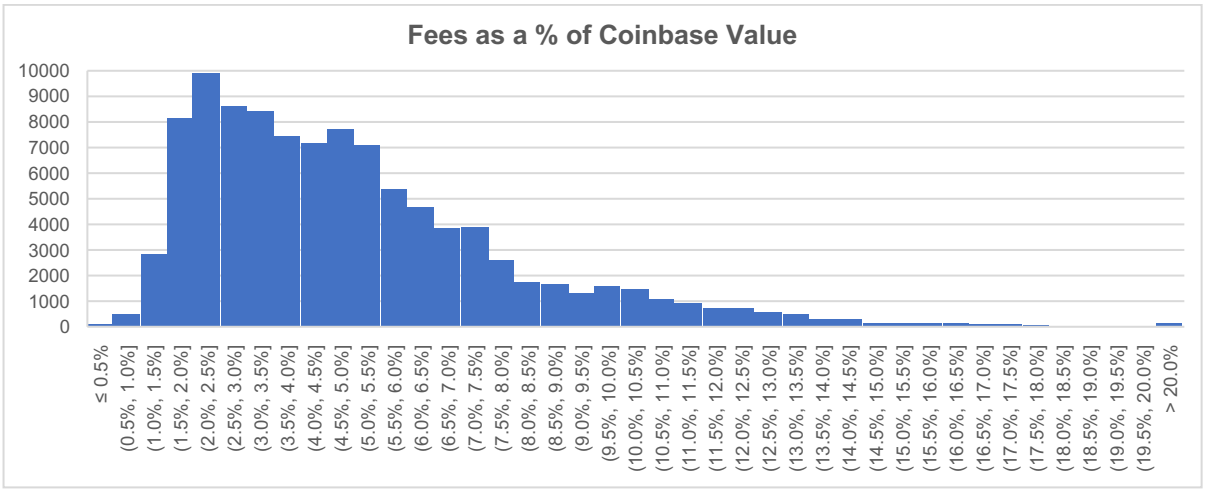
First, we sought to understand how many miners participated in each typical block during the period.

The below histogram shows that a significant majority of blocks, around 67%, have had 5, 6 or 7 miners. And about 28% of blocks have had 4, 8 or 9 miners. This means that about 95% of typical blocks have had between 4 and 9 miners, inclusive. The remaining 5% of blocks have had 1, 2, 3, or 10 or more miners.



We next examined fees miners paid in relation to the value of the Stacks coinbase. Overall, because a miner's fee payment does not affect the probability of them winning a block, the lower the fees they pay, the greater the opportunity to earn a mining profit.

[4] The Stacks community is currently considering various strategies to eliminate or minimize this MEV strategy by Bitcoin miners.

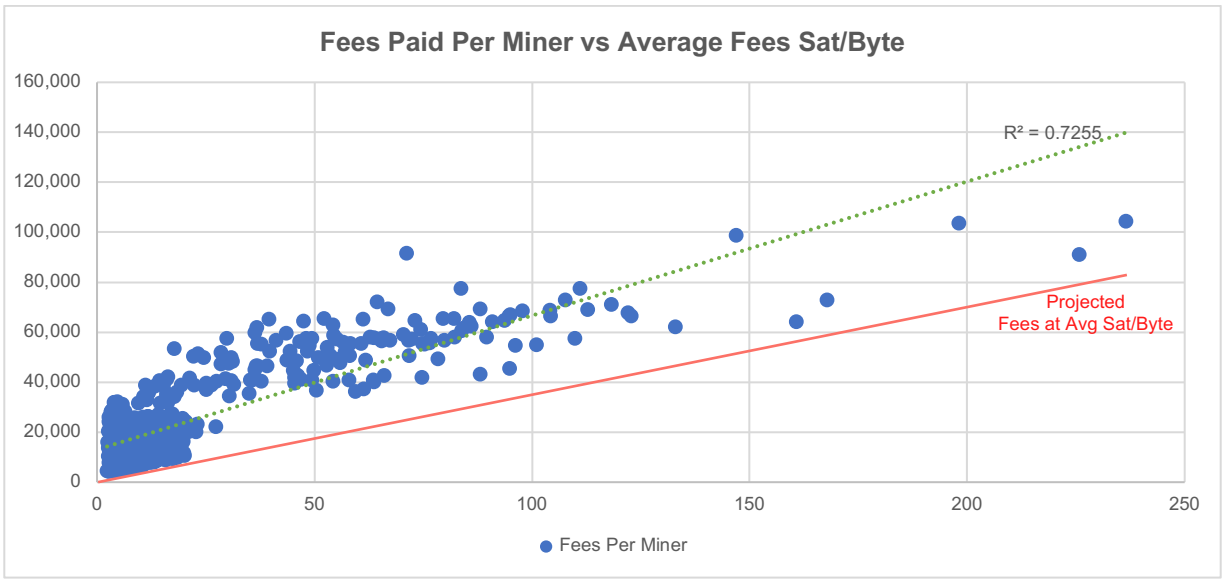


The average fees paid were at approximately 5.0% of the value of the coinbase, with the median at approximately 4.4%. For approximately 70.8% of blocks, the fees fell between 1% and 6% of the value of the Stacks coinbase.

We were then curious how the fees per miner for Stacks transactions related to the overall average fees for the Bitcoin network at the relevant time.

To do this, we first averaged our block data over 144 blocks, which equates approximately to a day. We therefore had the average fees paid per miner for approximately each day during the period, and we separately had the daily average fees paid for all Bitcoin transactions for each day (in Sats/Byte). A Stacks mining transaction is approximately 352 bytes.

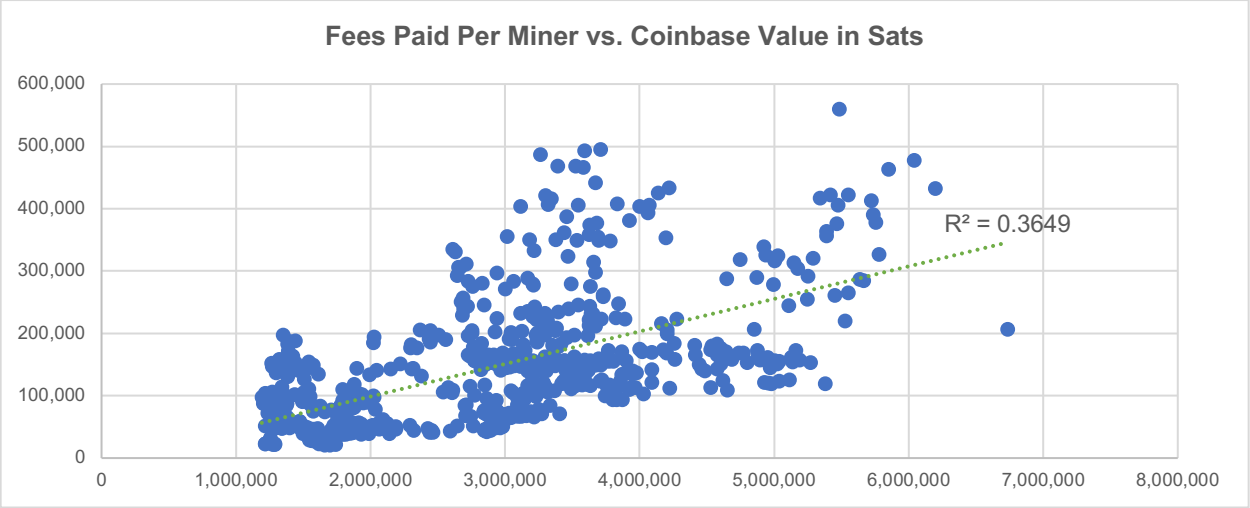
The below graph shows, in blue, the daily average fees paid per miner for Stacks transactions during the period. And, in red, shows the theoretical Stacks transaction fees if Stacks miners would have used the average Sats/Byte transaction fees for the Bitcoin network at the time they sent their Stacks mining transactions.



We see from the graph that the average overall Bitcoin fees appear to serve as a lower bound for the fees that Stacks miners pay for their transactions. Given that it's important that Stacks miners' transactions get included in specific blocks to participate in Stacks mining, it's not surprising that the fees paid by Stacks miners exceed average mining fees. Stacks miners are presumably paying a premium in fees to ensure inclusion in the necessary Bitcoin blocks.

Though there are few data points in the higher ranges, they appear closer to the average Sats/Byte line than the regression line. We could imagine that as fees become more expensive, miners may try to further optimize their fee spend, seeking to hew closer to the average spend than the generated regression. Ultimately, we believe that the average Sats/Byte would continue to serve as a lower bound for Stacks mining fees, with the regression line more likely serving as an upper bound, rather than an expected value, in higher ranges.

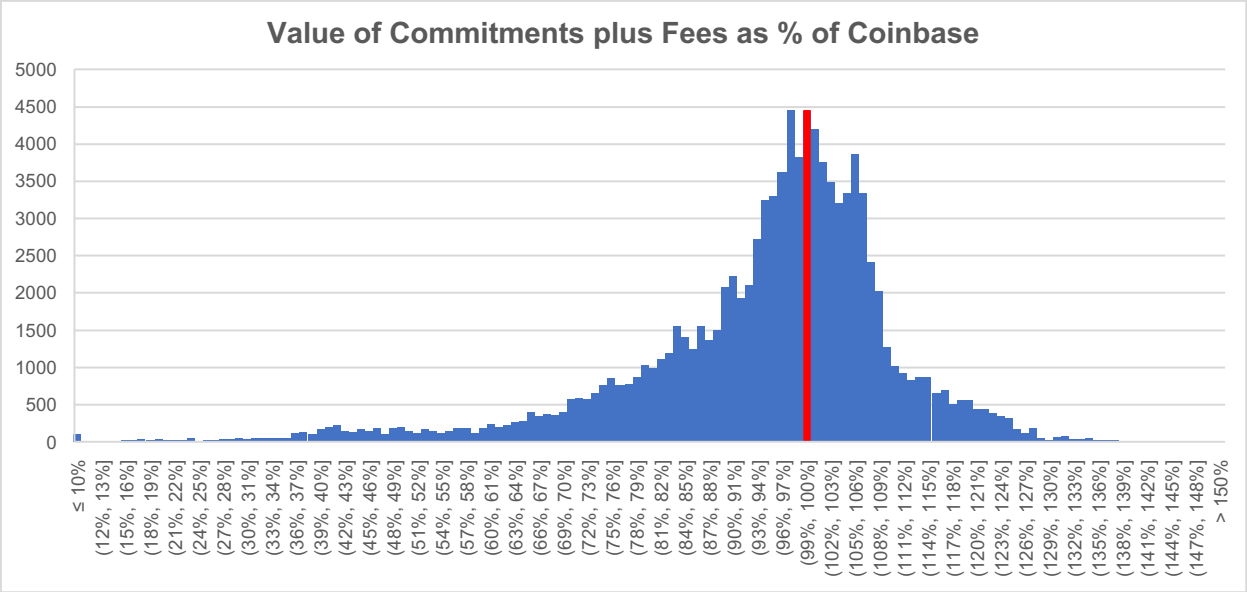
With respect to fees, we also want to consider whether there is any correlation with the value of the coinbase itself. We've charted these values below.



We would expect that the fees paid for mining transactions and the value of the coinbase to be largely independent, given Bitcoin fees are a function of Bitcoin network demand, and we see a fairly weak correlation in the graph above.

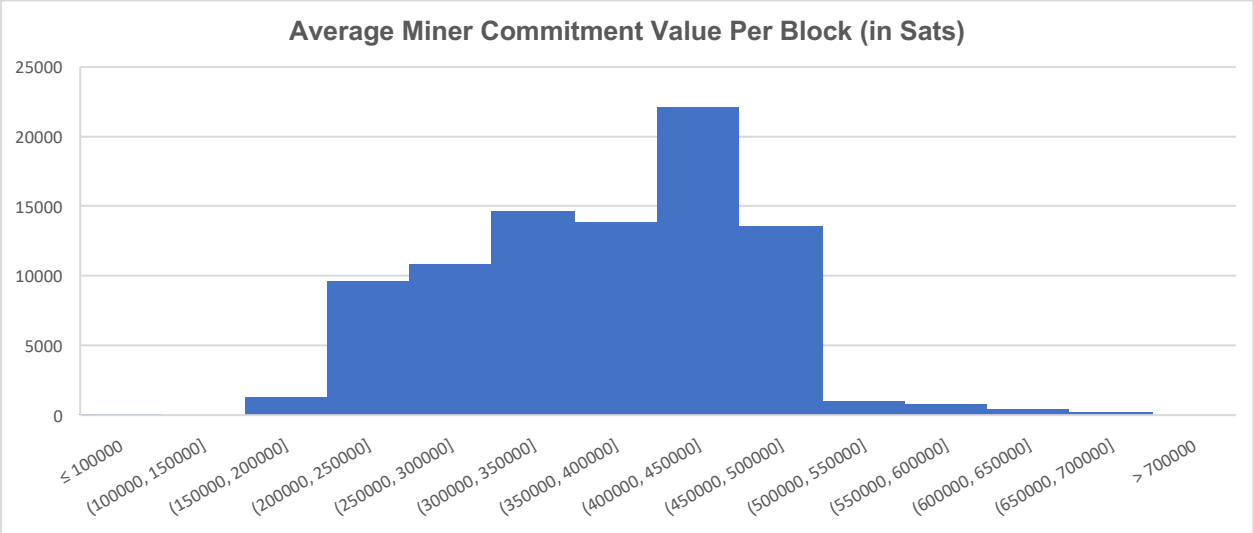
We next wanted to see the value of miners' commitments plus fees in relation to the value of the coinbase. We hypothesized that this value, in total, would settle just shy of the value of the coinbase.

In the below graph we've highlighted the (99% - 100%] range in red for easy visual reference.



The mean value of commitments plus fees was 94.2% of the value of the coinbase, with the median at 97.6% of the value of the coinbase. We see that the values of miners' commitments plus the fees they pay, in total, generally hovered around the value of the coinbase, ultimately skewed slightly below 100%. This skew is what allows miners to see a profit over the period.

We then wanted to see the average size of miners' commitments per block. The below chart shows the average commitments per miner from each block, excluding the first 100 days of mining.



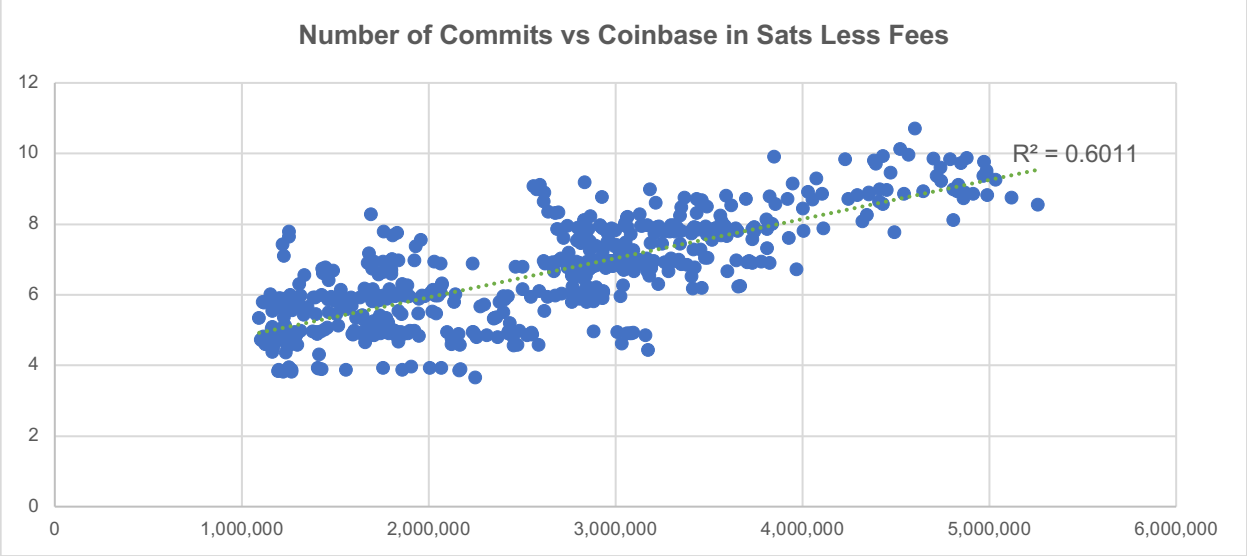
The mean average commitment per block was around 367,000 Satoshis, and the median was around 376,000 Satoshis. We see that 95% of blocks had an average miner commitment between 200,000 and 500,000 Satoshis.

We next sought to understand the connection between the value of the Stacks coinbase and the number of miners that participated in Stacks mining. Our hypothesis, as discussed above, is that the lower the value of the Stacks coinbase, the fewer miners Stacks mining supports.

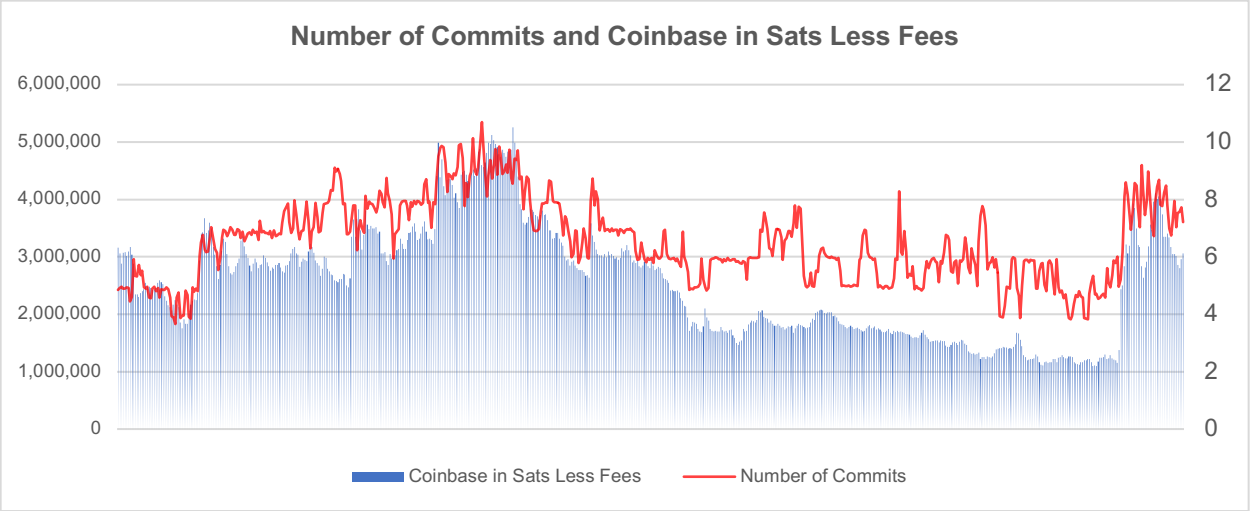
To take this a level deeper, though, what we really expect to see is that the value of the Stacks coinbase minus the fees paid by miners should dictate the number of miners that are able to participate. In other words, the amount of value, less fees, is what will determine profit potential and so should impact the number of miners that mining could support.

For this question, we again used the daily average data. We also trimmed the first 100 days of Stacks mining. We did this for two reasons. First, for most of that period, the Stacks coinbase reward included an initial mining bonus. This resulted in approximately 2466 Stacks per block being released to the winning miner each block rather than the standard 1000 Stacks per block. Second, it appears that mining behavior was more erratic over that period than what it appears to have settled into for the remainder of the examined period. We suspect that the significantly higher coinbase as well as the initial learning curve for miners, as they learned the new Stacks protocol, contributed to behavior in the first ~100 days that looks less like the behavior we see in the subsequent 600+ days. Given that we're more interested in the current and settled behavior of miners, and that the coinbase would never again approach ~2500 Stacks, we thought it was reasonable to exclude the first 100 days.

We see from the below graph that the number of commitments appear to be reasonably correlated to the value of the Stacks coinbase in Satoshis less fees.



Separately, we can see the correlation between commitments and coinbase value in the below chart, which shows these values as they've fluctuated over time.



While neither of these charts show a perfect correlation, there is a sound conceptual basis and apparent empirical basis, that show a connection between the value of the Stacks coinbase and the number of miners that participate in mining on the Stacks blockchain.

2.2.3 Summary of Key Conclusions

We believe the historical mining data tend to demonstrate a few likely conclusions regarding Stacks mining.

First, the total value of commitments plus fees from miners is, on average, about 94% of the value of the coinbase. This potentially implies about a 6% profit for miners. If we assume that Stacks mining is highly competitive, then this 6% profit could also potentially be thought of as equivalent to miners' opportunity cost in mining the Stacks blockchain. If miners are unable to obtain 6% profit, then they may begin to drop off from mining, or if mining returns are greater than 6%, more miners may join.

Second, the historical fees tended to stay in the low single-digits as a percent of the value of the coinbase. However, we see that fees are, unsurprisingly, significantly correlated with the average Bitcoin fees at the time they're made, and not significantly correlated with the value of the Stacks coinbase. We believe this could mean, for instance, that in the event that the value of Stacks decreases with respect to Bitcoin, and Bitcoin fees increase significantly, then the mining fees as a percent of the value of the coinbase could increase well above the single-digit percent we have historically seen.

Third, we see that the average commitment per miner tended stay between a range of 200,000 and 500,000 Satsohis. This could imply that even if the value of the Stacks coinbase became quite small, it may not be infinitely divisible by miners. Instead, miners may wish to see a baseline level of commitment on which they could earn a profit for it to be worth it to them to commit at all.

And, finally, we see that the number of miners appear to correlate fairly reliably with the value of the coinbase. As the value of the coinbase increases, the number of miners increase, and vice versa. We see this as intuitive (again, if a pie is smaller, fewer people will feel it's worth it to fight over a piece) and as a natural consequence of the various conclusions above.

Taken together, we do believe that if the value of the coinbase drops significantly, then the Stacks blockchain risks further, and significant, centralization. The value of the coinbase, though, is a function of both the number of Stacks released as part of the coinbase, and the value of those Stacks. In the next section we'll examine some potential pricing scenarios and their impact on centralization.

2.3 Stacks Pricing and Impact on Miner Centralization

An important component of this analysis is the consideration of the future value of the Stacks token itself. For instance, if the Stacks token price doubles the day of the coinbase halving, there would be no net effect for miners from the day before. And there would presumably be no effect from a miner centralization or security standpoint from the day before. Conversely, if the Stacks token price were to drop 50% the day of the coinbase halving, there would be a 75% drop in the value of the coinbase rewards from the day before. Such an outcome would presumably have considerable impact on miner centralization, the ability of malicious miners to manipulate the network, and the desirability of participating in Stacking.

Of course, we are not able to reliably predict the future value of Stacks tokens, and make no effort to do so. Instead, we should consider the possibility of various outcomes, and the potential impact on the Stacks blockchain.

We'll examine briefly what low risk, medium risk and high risk scenarios might look like with respect to Stacks value and its interplay with the halving.

There are three separate factors that ultimately affect the net coinbase value. As discussed, these factors are (1) the number of Stacks tokens released by the coinbase, (2) the value of Stacks tokens, and (3) the cost of Bitcoin fees.

If we assume that the halving moves forth as is currently planned, then we know that the number of tokens released as the coinbase will decrease from 1000 Stacks tokens to 500 Stacks tokens.

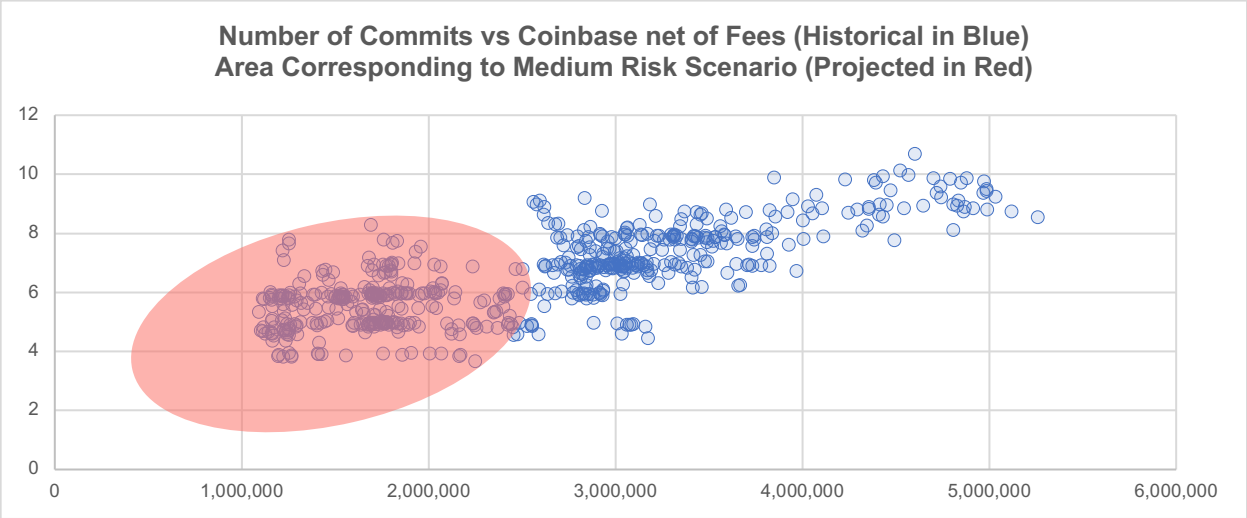
2.3.1 Medium Risk Scenario

For this initial scenario, which we'll refer to as the "medium risk" scenario, we'll assume that the future Stacks price and fees will continue to look like the historical Stacks price and fees.

Over the period we examined, the value of Stacks tokens ranged from a daily average of about 1060 Satoshis to 5400 Satoshis. This implies that the daily average coinbase value over that period was about 1.1m to 5.4m Satoshis. Although we believe fees are independent of the value of the coinbase, we'll assume for this scenario that they continue to be equal to about 5% of the value of the coinbase.

This ultimately means that, under this scenario with a block reward of 500 Stacks, the value of the coinbase would be expected to fall within the approximate range of 550,000 to 2.7m Satoshis. If we assume 5% in fees, then we would expect the net value of the coinbase, less fees, to be in the range of 525,000 to 2.6m Satoshis.

In the below graph, we've highlighted the area in red that roughly corresponds to where we would expect to see net coinbase value and the resulting number of miners we might expect to see given the historical data, and assuming historical Stacks price going forward.



As we can see, we would expect to see further reduction in the number of miners mining the Stacks network. Although this outcome may not be catastrophic, it does appear to exacerbate an already-existing issue with miner centralization.

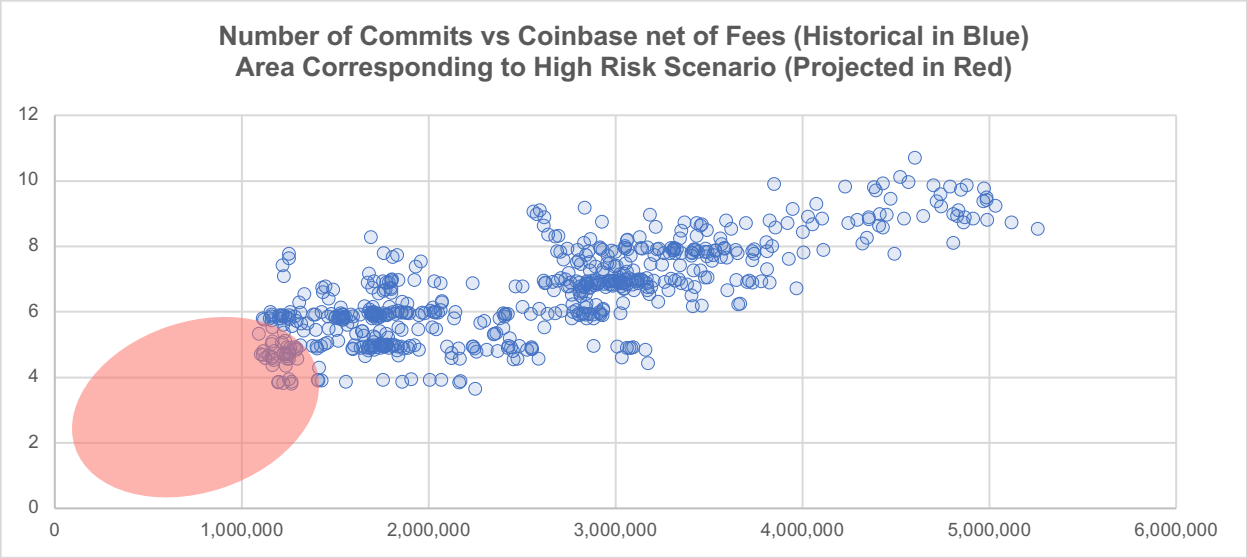
2.3.2 High Risk Scenario

We'll next explore a plausible, though relatively higher risk scenario than the previous. We'll assume that the value of Stacks tokens drops 50% relative the historical data. Under this scenario, with the halving going forth as expected, we'd expect the coinbase value to fall within the range of 275,000 to 1.4m Satoshis.

We'll also make the assumption that Bitcoin fees do not correspond to a percentage of the coinbase value, but rather operate independently based on Bitcoin network traffic. Historically we have seen incidence where the daily average Sats/Byte have exceeded 200. In such cases, we've seen the average fees paid per Stacks miners in the 100,000 Satoshi range.

With the recent adoption of new Bitcoin-based protocols (such as Ordinals), it may be the case that Bitcoin network transactions will increase in the future, and higher, sustained network fees may persist going forward.

If we assume a range of 10,000 to 100,000 Satoshis for fees for this high-risk scenario, we would expect a net coinbase value (less fees) to fall within a range of 175,000 to 1.4m Satoshis. We've highlighted this range in red in the below chart.

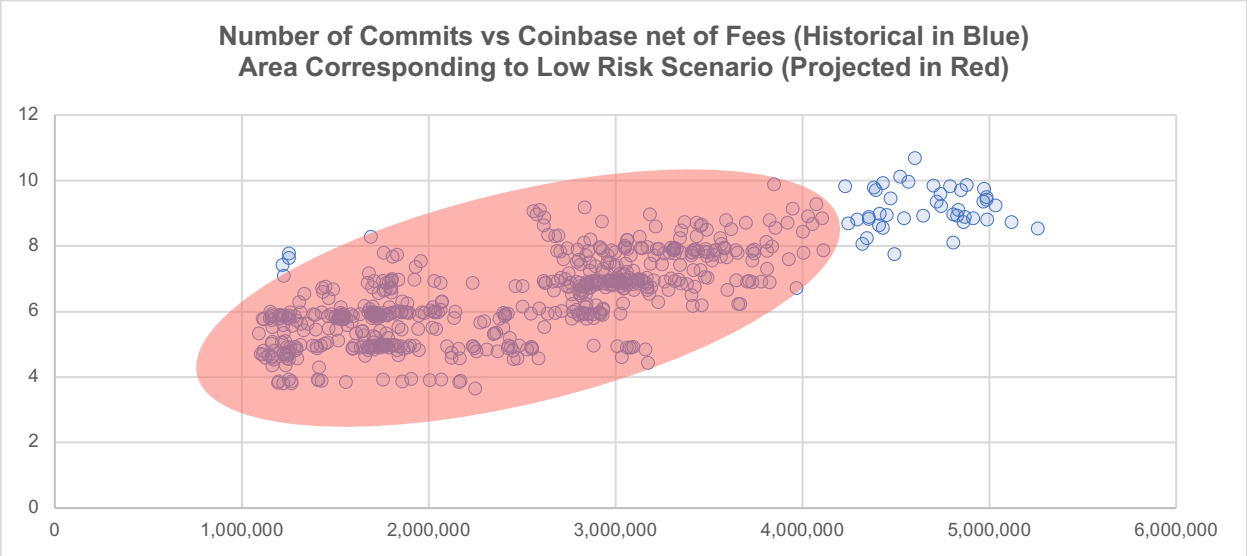


We see in the above chart a low expectation for the number of miners. Although it's unclear what the Stacks community might determine is a catastrophic level of centralization, this few number of consistent miners would likely be highly unsettling to the Stacks community and problematic for the network.

2.3.3 Lower Risk Scenario

For reference, we'll quickly examine the lower risk scenario where the Stacks price increases by 50% from historical values. This scenario would be largely in line with the current status, but we've included it here for completeness.

Under this scenario, the expected coinbase reward would be in the approximate range of 825,000 to 4,1m Satoshis. If we again assume 10,000 to 100,000 Satoshis in fees, the net coinbase would range from 725,000 to 4.1m. We've again graphed this range below in red.



We see the expected coverage is largely in line with the historical distribution, which is not unexpected given the net coinbase value largely matches the historical net coinbase value. While, again, this number of miners is less than ideal, given the current dissatisfaction with miner centralization, it would not appear catastrophic, as the current blockchain appears to be operating under conditions similar to these.

2.4 Implications for Security

For many blockchains, including Stacks, the block rewards allocated to miners can be thought of, in some sense, as a "security budget." The amount of incentive allocated to block rewards serves to disincentivize malicious miners from taking advantage of the system in various ways.

There are various versions of attacks or strategies miners could take to either advantage themselves or disrupt the system (examples of these include "double spend attacks" or "greedy miner attacks"). While we won't go into details regarding these strategies here, the main point is that if a malicious miner wishes to manipulate the Stacks blockchain in some way, they could seek to try to rewrite the blockchain history by building a longer fork than what currently exists off of a block in the past or they could try to ensure they win blocks going forward by making it difficult or uneconomical for other miners to participate.

In each of these cases, the cost for the malicious miner to engage in a malicious strategy is directly proportional to the value of the coinbase. If the coinbase is low in value, then the malicious miner must compete against a lower total-combined amount of competing mining contributions. This would make it easier for the malicious miner to win with a lower amount of capital. If the coinbase is high in value, the malicious miner must spend more money, competing against greater value from other miners, to successfully run an attack.

If we hold all else equal, such as Stacks price and Bitcoin fees, then the expected effect of the halving will be that a malicious miner will be able to run a malicious strategy for less cost.

While this consequence of the halving is not ideal, it is the natural consequence of *any* reward halving for any blockchain. It is not clear that the current level of block rewards is an acceptable security budget whereas post-halving, the block rewards would be an unacceptable security budget.

We believe that the main implication with respect to security is that the time to finality will, essentially, need to double. If before, one considered x blocks to be adequately settled, then it may make sense to wait 2*x blocks following the halving to consider a transaction final.

Also mitigating this concern is that with the upcoming Nakamoto release of the Stacks blockchain, it is currently planned that Stacks transactions will reach Bitcoin finality after 150 blocks.[5] This would mean that, regardless of the amount of the Stacks coinbase, after 150 blocks it would take a reorganization of the Bitcoin blockchain to manipulate Stacks blocks.

[5] There are other proposals that are currently being considered that would decrease the number of blocks to reach Bitcoin's finality to six blocks. This would further mitigate the issue and result in Stacks finality that is on-par with Bitcoin's. (*See here* https://forum.stacks.org/t/rfc-proposal-for-collaborative-mining-with-threshold-signatures/15176.)

This anticipated change would indicate that concerns around settlement time because of a decrease in coinbase value from the halving might be misplaced and ultimately be largely solved by the Nakamoto release.

2.5 Implications for Stacking

Stackers lock up their Stacks tokens for approximately two-week periods to earn Bitcoin rewards, which are sent by miners. Stackers retain custody of their Stacks tokens, but the tokens are locked from transfer during the period of Stacking.

Robust participation in Stacking is important as an indicator of network health and interest, as well as for the anticipated release of sBTC functionality. sBTC is a fully programmable, trustless two-way peg for Bitcoin. Many in the Stacks community see it as an important and valuable addition to the functionality of Stacks.[6]

For the purposes of this analysis, there are two ways in which sBTC relies on Stacking: First, Stackers (or a subset of them) will serve as the decentralized group of "signers" for sBTC, responsible for the pegging in and out of Bitcoin. Second, Stacks held in Stacking will, in a sense, be held as collateral for the Bitcoin that has been pegged in. There will be some ratio of Bitcoin value to Stacks value locked in Stacking (with the latter needing to be greater than the former), for the incentives of the sBTC system to function properly. Both of these require robust interest and participation in Stacking.

To date, Stacking has typically held hundreds of millions of dollars' worth of Stacks for each 2000-block Stacking cycle. The question we'll need to consider is, with a halving of the coinbase, will Stacking participation problematically decrease? We'll consider Stacking mainly from a conceptual perspective.

People are presumably incentivized to participate in Stacking to earn Stacking rewards. Stacking rewards are a function of the amount of Bitcoin sent by miners and the amount of total participation in Stacking. The amount of Bitcoin sent by miners is, in turn, a function of the number of Stacks tokens in the coinbase, Bitcoin fees, and the value of Stacks tokens.

If we make the simplifying assumption that the amount of Bitcoin distributed to Stackers by miners is 92% of the coinbase, which is what we've historically seen, then we can construct a simple equation for the annualized expected rate of Stacking rewards:

$$Rate\,of\ Rewards = 26 * \frac{0.92 * (Coinbase)}{2} \div \frac{Stacks\ Stacked}{2000}$$

This equation simplifies to:

$$Rate\,of\ Rewards = 23{,}290 * \frac{Coinbase}{Stacks\ Stacked}$$

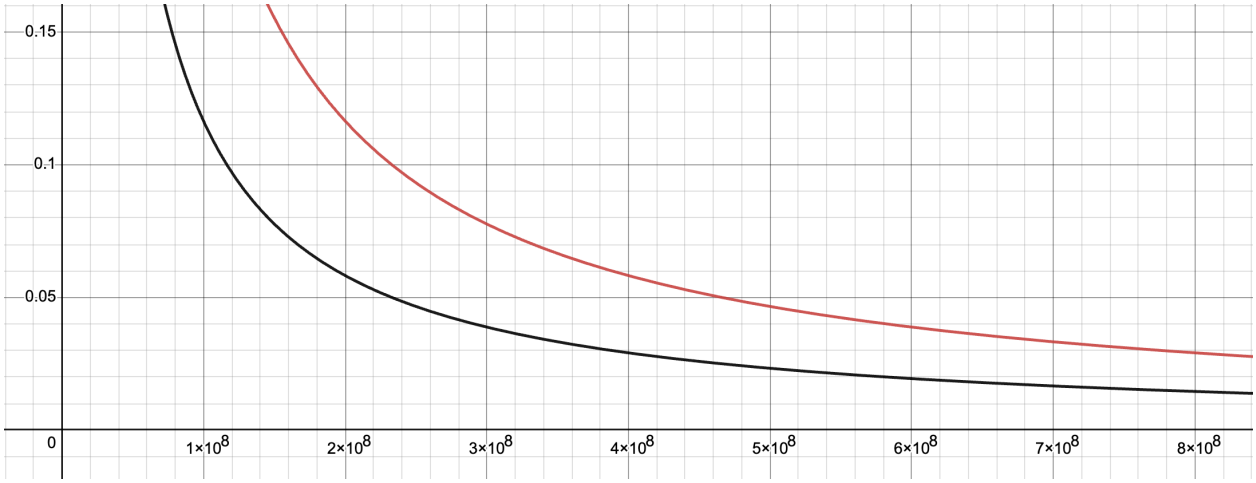
Note that both "Coinbase" and "Stacks Stacked" in the above equations are denominated in Stacks.

[6] To read more about sBTC you can visit the website https://sbtc.tech.

As an example, if the coinbase is 1000 STX and a total of 400 million Stacks have been Stacked in the Stacking cycle, then the expected annual rate of Stacking rewards would be about 5.8%.

Note that there are a few issues with the above equation. First, it essentially assumes that someone's Stacking amount, and total Stacks Stacked, are both multiples of the minimum Stacking threshold. Second, it doesn't account for changes in relative value of Stacks and Bitcoin over time, which can make a material difference. And third, the equation assumes one can continuously Stack for 26 consecutive two-week periods over the course of a year. There are, however, buffer periods that make that impossible.

Nevertheless, the equation is helpful in that it shows that if the coinbase were to be cut in half, we would in turn expect the annual rate of Stacking rewards to be cut in half as well. Here's a graph of two curves, one showing a coinbase value of 1000 STX (in red) and the other showing a coinbase value of 500 STX (in black). The x-axis is the total number of Stacks locked in Stacking and the y-axis is the expected annual rate of Stacking rewards.



As we can see from the graph, an alternative way to think about this difference in expected annual rate of Stacking rewards, is that if Stackers generally have a required rate of rewards, below which participation is not appealing, the number of Stacks that can be locked in Stacking is cut in half when the coinbase is cut in half.

As an example, if Stackers generally have a 5% rate of rewards requirement for participation, Stacking would only support a little over 200 million total Stacks as part of a Stacking cycle in order to reach that 5% when the coinbase is 500 Stacks per block. However, with the coinbase at 1000 Stacks per block, Stacking would be able to support close to 500 million total Stacks.

Given the significant expected reduction in the rate of Stacking rewards, we would expect that the halving will lead to a material decrease in the number of Stacks participating in Stacking.

This decrease will likely lead to a limitation on the amount of capital that can be locked in sBTC. Whether this limitation will lead to sBTC failing to reach its potential is unknown. However, a risk may be that a known, relatively low limit on the potential size of sBTC, may lead to it being viewed as an unattractive foundation upon which to build large-scale projects.

2.6 Considerations Against Making Changes

Up until now, we've focused mainly on potential risks of moving ahead with the halving. It's important, however, that we also consider potential risks and benefits with the halving moving ahead as planned. We'll discuss below a few key considerations that may weigh in favor of not making any changes to the emissions schedule. In the section immediately below, we'll discuss potential price benefits of the halving, and in the following section, we'll discuss some potential precedential issues that might follow from making a change.

2.6.1 Price Effect of the Halving

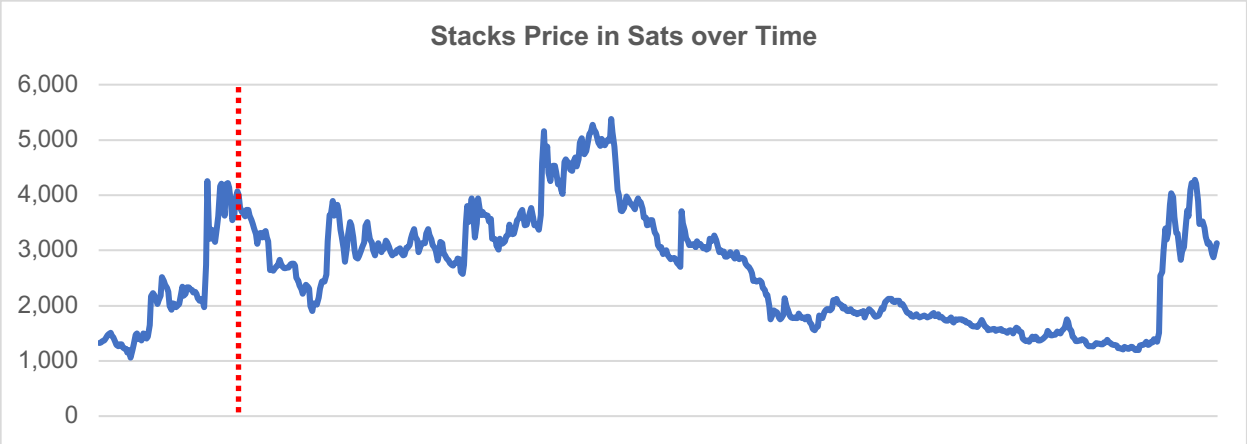
One might reasonably take the position that the halving itself will lead to an increase in the price of Stacks that will largely or wholly cover the decrease in the value of the coinbase that will result from the halving. If that were the case, then we would expect to see little effect on miner count or security issues from the drop in the number of Stacks issued as part of the coinbase. And, further, an adjustment to the halving may be misguided as a result.

This line of thinking essentially boils down to the idea that a high level of Stacks emissions creates sell pressure on the price of Stacks tokens by miners. If fewer Stacks tokens are emitted to miners, there would be less selling of Stacks tokens by miners, and therefore the price of Stacks tokens would naturally be higher.

We think it's accurate, and essentially uncontestable, to assume there would be some decrease in sell pressure because of the halving. However, it's impossible to know whether the effect would, in a material and sustainable way, increase the price of Stacks tokens.

We discuss below a few reasons why one might reasonably believe the halving won't have a significant positive price effect, and one reason why it might.

First, Stacks has had its own small "halving" experiment already. For the first couple months after the Stacks blockchain 2.0 went live, there was a mining bonus that released more Stacks per block than the standard 1000 Stacks. For nearly the first three months, 2466 Stacks were released each block. Then there was a sudden drop to 1000 Stacks per block. In the graph below, we've marked in red the approximate time when the block reward dropped from 2466 Stacks tokens per block to 1000 Stacks tokens per block.



We see the value of Stacks decreased considerably in the period immediately following the drop from 2466 Stacks per block to 1000 Stacks per block, and remained at or below its price at the time of the reward drop. This is the exact opposite of the behavior we would expect to see if a halving were to be expected to result in an increase in price.

In the upcoming halving, there will be a drop of 500 Stacks per block being released, whereas in this previous drop at the end of the bonus period, a full 1466 fewer tokens per block were being released. The drop in newly-minted Stacks tokens at the end of the bonus period was significantly greater than what we would see with the upcoming halving.

The price effect of a halving should theoretically correlate with the amount in the drop of the block reward (the bigger the drop, the bigger the price effect) and inversely correlate with the number of outstanding tokens at the time of the drop (the greater the circulating supply, the lesser the price effect). Both of these factors should indicate a greater price effect as a result of the initial bonus halving than for the upcoming halving.

Second, we should consider the actual value of Stacks tokens being released on a daily basis in comparison to the daily volume of Stacks tokens being traded on crypto markets. If we look at the last thirty days of Stacks token trading, the mean and median daily trading volume, according to Coinmarketcap, were $92m and $47m, respectively. In addition, the mean and median opening price for Stacks tokens were $0.61 and $0.60.

We have no particular reason to distrust the volume numbers presented by Coinmarketcap, but understand there is limited confidence in volume numbers reported by some markets. Given this, we'll assume volume numbers that are reduced by 50% from the reported ones. We'll therefore assume the mean and median trading volume over the last 30 days were about $46m and $24m, respectively.

At a price of $0.60, approximately $86,400 of Stacks tokens are released to miners each day. If miners sold all Stacks tokens on the day they're earned, then over the last 30 days, the sales from mining emissions each day corresponded to approximately 0.19% of the mean day's volume and 0.36% of the median day's volume.

If we assume these assumptions would continue to hold, and the halving were to proceed as expected, then the sales from mining emission each day would decrease by half, corresponding to about 0.1% of the mean day's volume and 0.18% of the median day's volume.

While we are not trading experts, and can't make high-confidence conclusions here, we would be surprised if this minimal decrease in daily selling pressure had significant impact, in itself, on the trading value of Stacks tokens.

Despite all the above, we believe the halving may potentially have a significant and sustained effect on the value of Stacks tokens. One reason this might be the case, despite the historical indications and certain fundamentals seeming to indicate the contrary, is that there could be a powerful narrative effect of a halving.

Halvings have long played a significant role in the theme around Bitcoin bull market cycles. It's unknowable whether the price increases that appeared to correlate with these halvings were the direct result of the structural decrease in Bitcoin emissions, the power of the story of the halving, other factors entirely, or a combination of all of these.

We don't want to discount the possibility that, despite some potential reason to believe the immediate and direct effect of a decrease in Stacks emissions might not impact the price considerably, the power of the story of the halving could lead to a more significant price impact. Ultimately, prices of assets go up if there's greater demand to purchase than there is supply being sold. A widespread and strong belief that a halving could positively effect price could, in itself, create demand such that price increases.

This could be the case even though we did not see a price effect with respect to the bonus period "halving" early in Stacks' existence. If we assume that the price effect of a Stacks halving might be more the result of the narrative around the halving than the structural change in emissions, then we would not have expected much impact of the bonus period ending. In that case, as far as we're able to tell, there was not widespread discussion or narrative around the decrease in Stacks emissions at the ending of the bonus period. Few people outside of miners likely knew about it.

Our takeaway is that while we believe it's possible the halving could result in a significant and sustained increase in price for the Stacks tokens, we think it would be misguided to rely on that outcome. Markets are finnicky and unpredictable in all circumstances. While we do not think the historical data or the structure of Stacks markets point to a likely significant effect, narratives in themselves can be quite powerful. This all points to the conclusion that whichever approach the Stacks community decides to take, it should not assume that the halving will necessarily result in a price increase that will solve all issues.

2.6.2 Precedential Issues

We will now discuss the question of whether, even if it might be advisable to make some change to the Stacks emissions schedule for the benefit of the Stacks network, should it not be made at all, given potential consequences of making a change of this type and magnitude.

A particular argument against a change that adjusts the emissions schedule may be along the lines of:

- If the Stacks community makes a change to the emissions schedule now, they'll just try to do the same thing again in the future.

Another version of this concern maybe a broader slippery-slope argument along the lines of:

- If the Stacks community makes this change, who knows what other big, disruptive changes it may try to push for in the future.

We believe these concerns are likely misguided. If Stacks was trying to replace Bitcoin, with a similarly stable, unchanging foundation, these critiques may carry some more weight. However, in part, the point of Stacks is to be a more flexible, programmable layer on top of Bitcoin. This means that Stacks needs to inherently be more flexible and experimental. The philosophy is that Stacks pushes the complexity up the stack and keeps it away from Bitcoin. But to achieve the goals desired for Bitcoin as a whole, complexity must reside somewhere.

Stacks is in its relative infancy. The Stacks community still needs to figure out how best to achieve its goal of creating the infrastructure for a fully programmable Bitcoin layer. As

Stacks continues to grow and be used, data is being created to for the Stacks community to consider how Stacks should continue to evolve.

We believe it would be a mistake to reject a change to the emissions schedule solely based on the fear that it may make future changes more likely. Indeed, the Stacks community choosing to make a change based on what it sees as a need for the network should be thought of as a feature and strength of the Stacks community, and not a problem.

That said, there may be good reasons not to make a change to the emissions schedule that are not contemplated by this paper. We've sought to be comprehensive, but there are surely further considerations outside of what we've discussed here. However, we do not believe the reason should be based on an artificial need to be inflexible, or the fear of a slippery slope.

3 Conclusion

3.1 Review

To briefly recap, we sought to examine some potential risks of the coinbase halving moving forward as anticipated early next year. To do that, we created a simple theoretical framework for how we would expect mining to operate on the Stacks blockchain. We then examined the historical data for mining, from which we made some conclusions regarding mining behavior.

We saw that as the value of the Stacks coinbase decreases, the number of miners appear to decrease as well. We then showed some potential outcomes for miner count under a few different Stacks price scenarios, and saw that there could be a material risk of even further miner centralization than we see now.

We then briefly examined the implications for security, more broadly, for the Stacks blockchain because of a decrease in the value of the coinbase. We saw this as a lesser risk, given that the primary consequence will likely be a need for longer confirmation times. And the need for longer confirmation times might be negated by the forthcoming Nakamoto release, which will allow for Bitcoin finality after a certain number of Stacks blocks.

Next we examined potential consequences of the halving for Stacking, and saw that a 50% drop in the coinbase reward would mean an approximately 50% drop in Stacking rewards. We believe the amount of Stacks participating in Stacking might decrease significantly as a result. This may be a mild risk to the network in that it may demonstrate a lack of enthusiasm or interest in the network, but may also be a more significant risk to the extent it may limit the amount of capital that can be locked up in sBTC. If sBTC cannot support significant capital, then it may not reach the adoption hoped for or anticipated by the Stacks community.

We then considered some arguments that may support not adjusting the emission schedule at all. First, whether the halving itself would lead to a price increase that would largely negate the decrease in the coinbase value that we've modeled. While conceivable, we would be reluctant to rely solely on that outcome to negate the various concerns discussed above. And second, we considered whether such a significant change to the emission schedule should simply not be allowed because of the precedent that it might set. We believe that the Stacks community showing adaptation to data and circumstances is a positive attribute, and not a significant risk.

3.2 Recommendation

We believe the Stacks community should strongly consider a delay to the halving anticipated to take place next year, and consider, debate, and adopt adjustments to the Stacks emissions schedule that would allow it to do so.

We believe the appropriate framework for the Stacks community to consider as to whether it should adjust the mining emissions schedule is to evaluate which path maximizes its potential for network success and minimizes its risk.

The Stacks network is still at a relatively early stage in its existence, and should adjust its structure in ways that match its developing needs, provided such changes are supported by its community.

The coinbase halving for the Stacks network is anticipated to occur in January 2025. With it, we see two significant risks:

1. Miner Centralization. Miner centralization is already a problem on the Stacks network. For 95% of the blocks mined on the Stacks network so far, there have only been between 4 and 9 miners. The halving will exacerbate this problem, potentially decreasing the number of miners by half or more. Moreover, as of late new application on Bitcoin itself have shown the potential for increasing Bitcoin fees. If Bitcoin fees were to continue to increase, we would expect that even fewer miners, independent of the coinbase value, would be able to profitability mine on the Stacks blockchain, leading to even greater miner centralization.

2. sBTC Success. sBTC functionality will be heavily intertwined with the Stacking functionality. Most importantly for our purposes, the amount of Bitcoin that can be held as part of the sBTC protocol will be directly related to the amount of Stacks held in Stacking. For Stackers to want to lock up and hold their Stacks in the Stacking protocol, the rate of Stacking rewards must be attractive enough for them. Unfortunately, we would expect that the halving will cause a significant decrease in the rate of Stacking rewards, potentially leading to a signficiant decrease in Stacking participation. If that were to occur, the viability of sBTC as a system that could support large-scale projects could be in jeopardy.

There may be other ways in which the Stacks network could solve both of these issues, but for the moment some delay in halving appears to be a relatively simple and low-risk approach for mitigating them. Such an approach may also provide sufficient runway for the Stacks community to consider and implement other solutions to these issues that don't rely on emissions to mitigate them. Other than some broad, ecosystem-wide dilution (the amount of which would depend on the exact approach to delaying the halving), there appears to be little downside to making a limited, time-bound emissions adjustment.