LUMOS

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Valuing Bitcoin

Modeling the price of bitcoin as a monetary asset through market forces

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Introduction

After investors have learned the basics of bitcoin, they often ask, “how is it possible to own an asset if they are unable to determine what its fair value should be?” Valuation methods vary widely across a variety of assets, from traditional cash flowing businesses to physical commodities. Valuation can be straightforward and simple, or cumbersome and complex depending on the asset class, model, and users’ preference. Regardless of the method, investors should always aim to maintain some type of framework for which they can value assets that are being considered for investment in their portfolio. Only then can they decide whether that asset is expensive or cheap relative to their estimation of its current and potential future value.

In this piece, we unravel how one may use their understanding of bitcoin’s unique characteristics to help inform valuation. As mentioned in our prior research, we believe that bitcoin is best understood as an emergent monetary asset, and therefore the optimal approach for determining long-term fair value could potentially be derived through the analysis of its supply and demand curves. As discussed throughout the paper, the combination of bitcoin’s predetermined supply schedule and its technology-like adoption curve makes the use of Metcalfe’s Law one of the most compelling valuation techniques available.

This paper can be largely summarized through the following ideas:

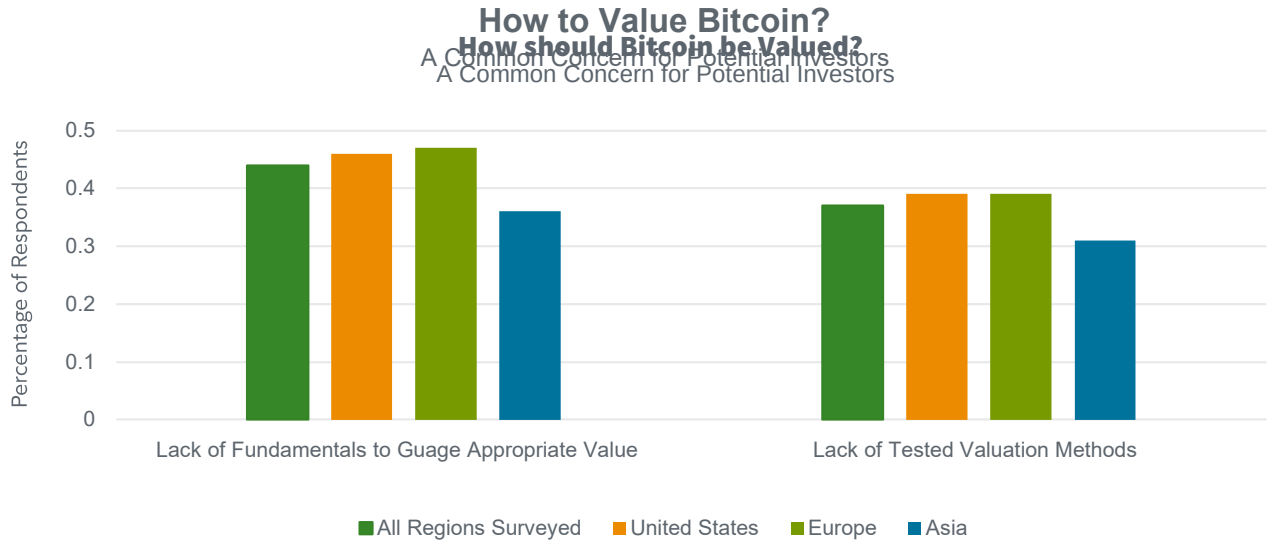
- **Having a framework for which to value any investment opportunity is a necessity**: Bitcoin represents a non-sovereign monetary asset with no cash flows or industrial use case and therefore derives its value through its relative attractiveness as an alternative store of value. As a result, we believe supply and demand curves largely drive its long-term value.
- **Bitcoin’s supply is predetermined, increasing in scarcity and is inelastic to changes in demand**: The stock-to-flow model gained popularity as a supply-side only valuation model for bitcoin. Despite its historic popularity, we do not necessarily see use of the model on a standalone basis for forward price expectations. It does however highlight an important supply imbalance created by each subsequent halving event, though these are likely to be less impactful as they have been historically given bitcoin’s issuance is already relatively low.
- **Network effects have shown to be important in the age of technological innovation**: Successful emerging technologies often exhibit steep S-shaped adoption curves and undergo periods of rapid user growth. Evidence suggests that an increase in the number of users to a given network can, and does, have a direct relationship with the value of that network. [1] Cell phone and internet adoption provide a useful proxy for the estimated future growth in the adoption of bitcoin and are potentially useful in helping to estimate future adoption and price.

1 https://ieeexplore.ieee.org/document/6636305

- **A shift in importance from the supply curve to the future demand curve has likely emerged**: Modeling bitcoin via a demand-side method, although sensitive to the implied network adoption rate, delivers a potentially useful framework for the ascension of a new, digital store of value coming into fruition this decade. Indeed, in our view, bitcoin's adoption curve is likely to be one of the most important drivers of value accrual over the coming years.

Bitcoin Valuation Concerns

Bitcoin is a category creator. [2] It breaks the mold of many traditional investments and is undoubtedly polarizing and controversial, not too dissimilar from new technologies or discoveries of the past. Given the abnormalities of bitcoin relative to many traditional investments, it is rather unsurprising that "lack of fundamentals to gauge appropriate value" was the second highest-ranked barrier to adoption amongst surveyed investors in the Lumos Digital Assets ℠ 2021 Institutional Investor Digital Asset Study, followed shortly thereafter by "lack of tested valuation methods". The inability to determine what bitcoin should be worth is seen as a flaw that often prevents investment entirely, or drastically limits a given investor's allocation to an insignificant and speculative position size.



Data Source: Lumos Digital Assets ℠ 2021 Institutional Investor Digital Asset Study.

Investors in any asset class work to construct a framework through which they can interpret that given asset's fair value. The framework and modeling are different depending on what type of investment is being considered. For much of the traditional investment world, this exercise is straightforward and heavily reliant on a few key assumptions made by an analyst. In the equity space, this often requires projecting an estimated free cash flow growth rate and a discount rate. For traditional commodities, analysts must consider supply and demand factors, with both inputs being subject to change at a moment's notice.

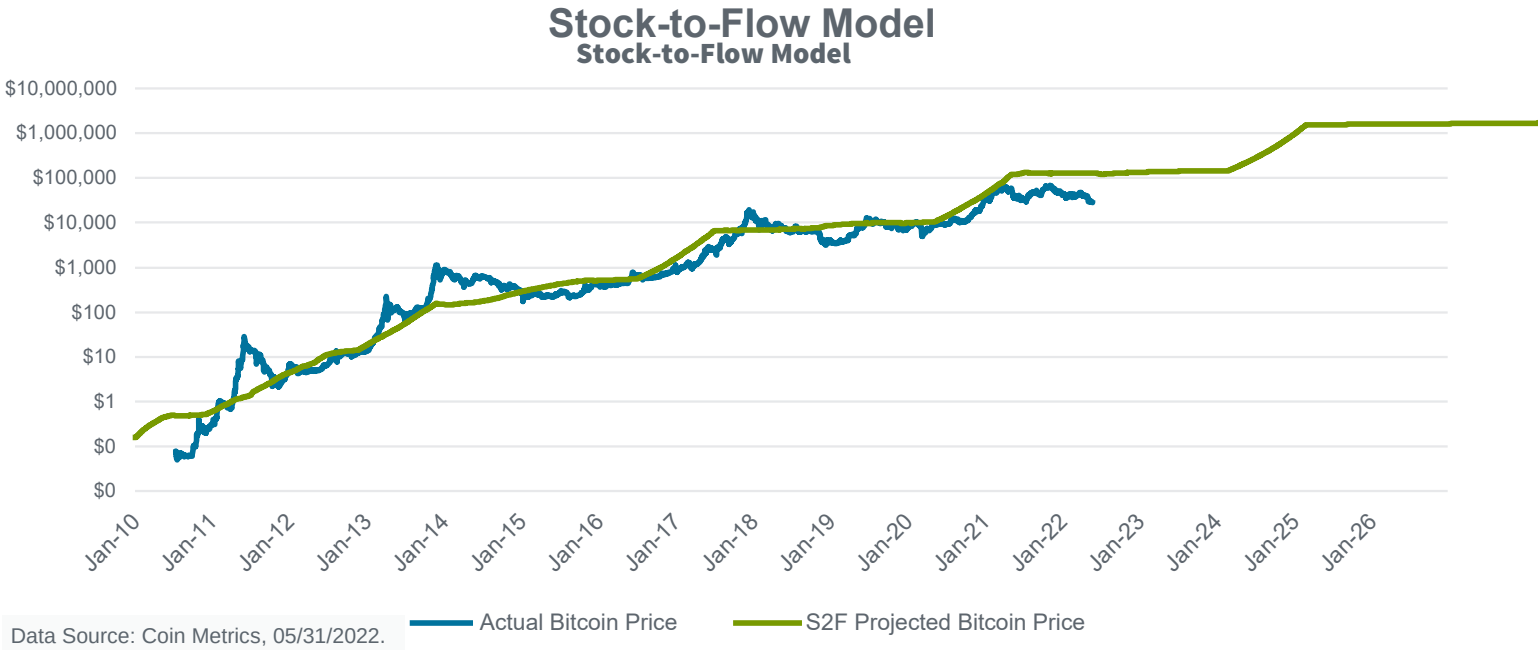
2 https://www.forbes.com/sites/spencerbogart/2017/12/03/bitcoin-is-a-platypus-the-story-of-category-creators

For bitcoin, it's a bit different. Bitcoin is representative of both a monetary asset, as well as a technological advancement in money. Therefore, understanding the asset's supply and demand curves is critical, seeing that it is solely a monetary asset with no cash flow or industrial use case like commodities such as gold. In bitcoin, the existing and future supply curve is predetermined and knowable. For this and other reasons discussed later, we particularly focus on bitcoin's technological-like adoption curve as a key input to determining its potential fair value.

Supply-Side Valuation

The concept of modeling bitcoin's price based on scarcity became heavily popularized between 2019 and 2020. The future issuance of bitcoin is known with near certainty, allowing for pricing models based solely on supply to reflect projections into the future. Bitcoin's stock-to-flow model became best known by an anonymous investor, known as Plan B. [3] Stock-to-flow is a concept that predates digital assets and has historically been referenced to explain the relative scarcity of various commodities such as precious metals. [4]

Simply put, stock-to-flow is a measure of scarcity for any given commodity. An asset's "stock" represents its outstanding supply, and its "flow" represents the net new annual issuance of that commodity. Assets like gold, known for their scarcity, exhibit high levels of outstanding stock relative to their new annual flow, otherwise phrased as having a high stock-to-flow ratio. Plan B created multiple iterations of pricing models based on bitcoin's changing stock-to-flow ratio as the sole input, and a historical relationship that existed between the asset's price and its scarcity, measured via its stock-to-flow ratio.



Data Source: Coin Metrics, 05/31/2022.

3 https://medium.com/@100trillionUSD/modeling-bitcoins-value-with-scarcity-91fa0fc03e25

4 https://ingoldwetrust.report/the-stock-to-flow-ratio-as-the-most-significant-reason-for-golds-monetary-importance/?lang=en

The backtested data for the stock-to-flow model is compelling, and the high correlation shown historically could lead one to conclude that the relationship between price and scarcity will persist per the model's outputs. However, correlation does not necessarily equal causation when simply comparing two sets of time series data. The traditional stock-to-flow model requires cointegration, a way to show the relationship is unlikely to be an act of randomness between the two sets of data to argue that the model is statistically likely to persist on an out-of-sample basis. There has also been substantial debate around whether or not the various models proposed by Plan B require or exhibit cointegration [5], or a way to show the relationships is unlikely to be an act of randomness. As a result, it may not yet be possible to say whether this relationship should hold out-of-sample.

Additionally, supply curves being the only input to derive value does not make sense on a fundamental level either. An asset, good, or service's ability to fulfill a need, such as the need for a better form of money, would likely be reflected in its demand curve. Scarcity alone cannot drive value without a valid use case and market demand for said use. This is not to argue that scarcity does not play an important role in the pricing of bitcoin. Rather, it is to argue that only considering supply while neglecting changes in the asset's demand curve would be missing a key element to bitcoin's marginal pricing today, particularly given that bitcoin's issuance rate continues to diminish in impact relative to its total outstanding supply.

Stock-to-Flow Changes – Still an Important Concept to Understand

Bitcoin's halving events have been followed by large price runs in each year or so following the preprogrammed, quadrennial event. These halvings are the result of bitcoin's predetermined issuance schedule, automatically lowering its issuance rate roughly every four years, which correspondingly raises its stock-to-flow ratio. In early years, this halving event appeared to have caused a larger imbalance between the outstanding issued supply and total demand for bitcoin. Each subsequent halving event has been followed by a reduction in newly issued supply that is likely less impactful to the imbalance between supply and demand and has been followed by price increases that are less dramatic.

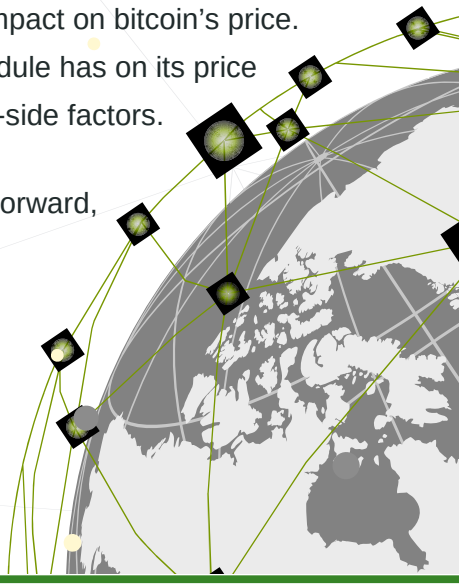
Halving Event (Date)	Stock-to-Flow Ratio	Annual Inflation Rate	Daily BTC Issuance	2-Year Forward Returns
1st Halving (2012)	12.5	8%	3,600	2,964%
2nd Halving (2016)	25	4%	1,800	922%
3rd Halving (2020)	50	2%	900	348%

Data Source: Coin Metrics, 05/31/2022. Note that stock-to-flow, inflation rate, and daily issuance are simple estimates. The lagging issuance rate shifts throughout the period, which causes these figures to slightly change throughout the duration of each halving epoch.

5 https://medium.com/amdax-asset-management/reviewing-modelling-bitcoins-value-with-scarcity-part-iii-the-fall-of-cointegration-ec5a8267098a

The incremental impact of each halving event appears to have had a diminishing impact on bitcoin's price. The potential reduction in influence that the future changes in bitcoin's supply schedule has on its price has led to, in our view, a shifting of importance from supply-side factors to demand-side factors.

Although the stock-to-flow model may have less of a use as a valuation tool going forward, its fundamental drivers are useful to remember. If bitcoin can maintain a growing technological-like demand curve alongside its shrinking inflation rate, then the only corrective factor left would be an upwards adjustment in its marginal pricing.



Demand - Network Effects

Network effects have become a key component to the operating model of many businesses. They represent the idea that the level of utility or perceived value from a particular good or service is a direct result of the number of users of that very good or service. For instance, a fax machine or cell phone is quite useless without additional users utilizing identical or similar technology. Therefore, the level of utility that a cell phone is capable of representing is directly linked to the total number of individuals that also own and operate one. An increase in the number of users represents an increase in the potential value provided and raises the incentive for others to purchase a cell phone. Today, cell phones are ubiquitous throughout society and offer multiple mediums for which individuals can communicate to one another.

> A monetary good or network with no general acceptance or broad recognition for its value proposition would be a lousy place to store value and likely unusable as a medium of exchange. Gold has obtained strong network effects over thousands of years, and individuals all around the world recognize it as a scarce, durable, and generally accepted store of value asset.

Modern Examples of Network Effects

We witness and use technologies based on network effects daily, often without recognizing it as one of the core reasons that we use that given good or service. Social platforms such as Facebook, Twitter, Instagram, and LinkedIn each offer their own unique value proposition for communicating and sharing content, but their competitive advantage relative to direct competition is strong due to network effects associated with the number of users that enjoy these platforms today.

Ridesharing applications such as Uber and Lyft operate with very little outside competition as it is difficult to get both individuals searching for rides as well as drivers willing to facilitate them at the exact same time. The technology that Uber and Lyft represented at the time had to be far superior to traditional taxi cabs to

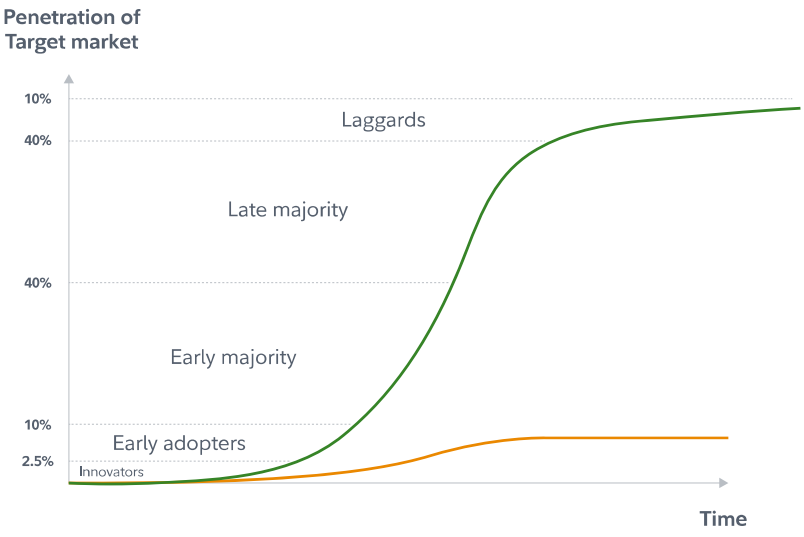
gain traction and begin creating the strong networks that exist today. Now, it's nearly inconceivable that a service like Uber or Lyft would not exist. The value of these networks increased rapidly in their early days, as each marginal user and driver represented another individual opting into this service who would later be searching for, or providing, a ride in any given location and at any given time. Network effects are powerful, create competitive moats, and drive value.

Metcalfe's Law

Number of Users	Number of Connections
2	1
5	10
25	300
100	4,950

In 1993, a direct connection between the value of a telecommunications network and its number of users was formulated. [6] This formula, known as Metcalfe's Law, is a method for explaining the phenomena of network effects driving value that we can see in many of the businesses we enjoy today. The equation is quite simple – the value of a telecommunications network is directly proportional to the square of the number of users of that system. This equation can, and has been, applied to many of the less tangible business models that live on the internet today. [7] The increase in usability for a system where network effects play a role becomes evident very fast, such as the simple exercise shown above.

It is rather easy to see the additional value that accrues to a network as more users onboard. Each unique user is then connected to all other users, which creates compounding growth for the number of connections that are possible on that network and broader acceptance amongst the general population for that given technology.



Data Source: Diffusions of Innovations by Everett Rogers.

Adoption Curves

Network effects tend to drive an adoption curve that looks similar across various successful technologies. This adoption curve, known as an "S-Curve", due to its S-like shape, can be simply explained through the logic of adoption trends. [8]

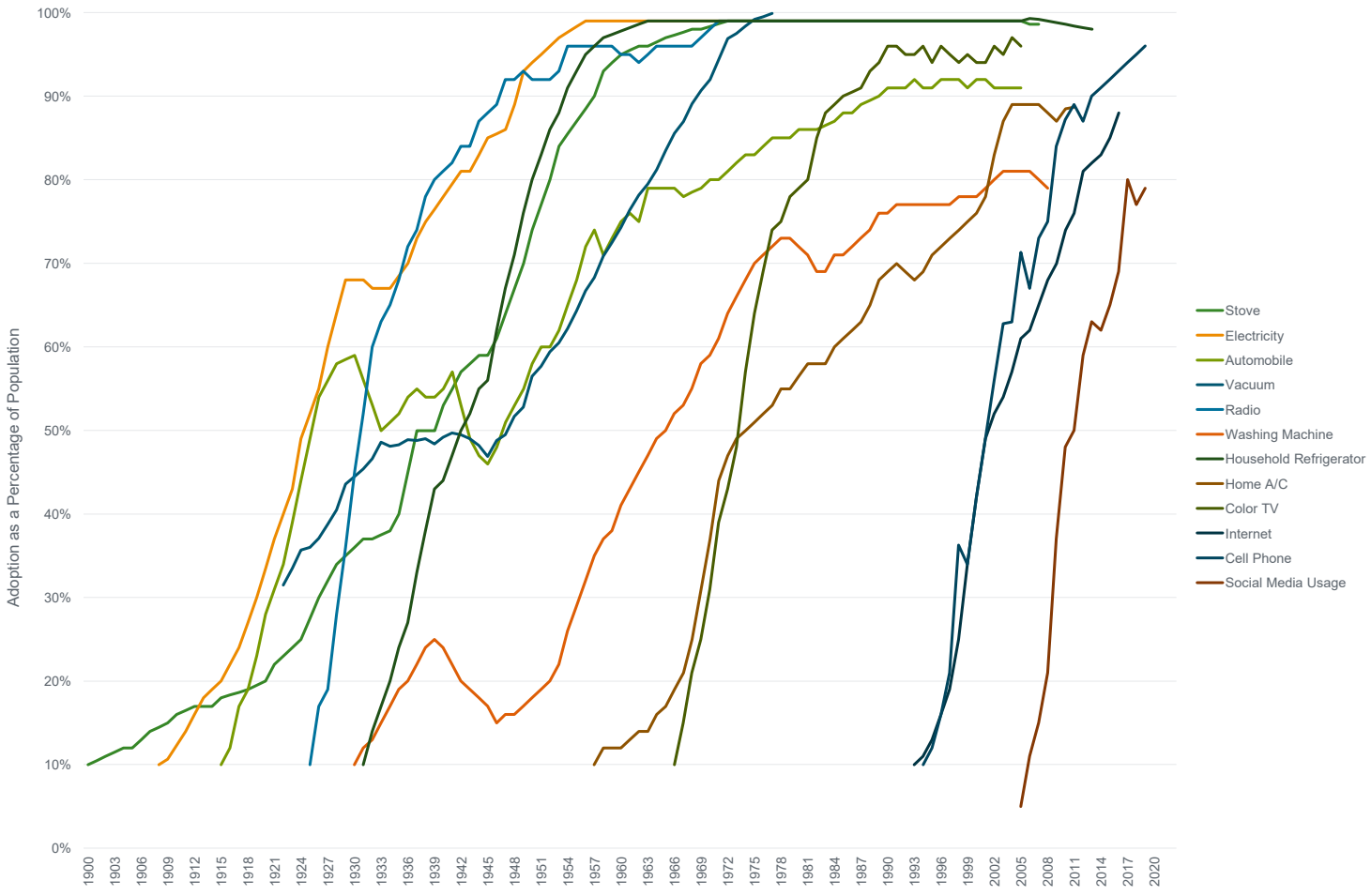
Early adopters to a given technology often see current and potential future value in that network even though it is not yet widely used. Over time, if a technology displays a large enough advantage relative

6 Carl Shapiro and Hal R. Varian (1999). Information Rules. Harvard Business Press: 184.
7 https://www.researchgate.net/publication/273895436_Tencent_and_Facebook_Data_Validate_Metcalfe's_Law
8 Rogers, Everett M. 1995. Diffusion of innovations. New York: Free Press.

to its incumbents, and switching costs are low enough, then adoption will begin to compound. This is when a technology begins to reach a critical mass. This period is when technological adoption curves exhibit strong changes in convexity and the number of its users quickly compounds. Finally, as it becomes generally accepted as a superior and widely used technology throughout society, the product or service begins to show a decrease in its rapid adoption rate, forming an asymptote near full maturity.

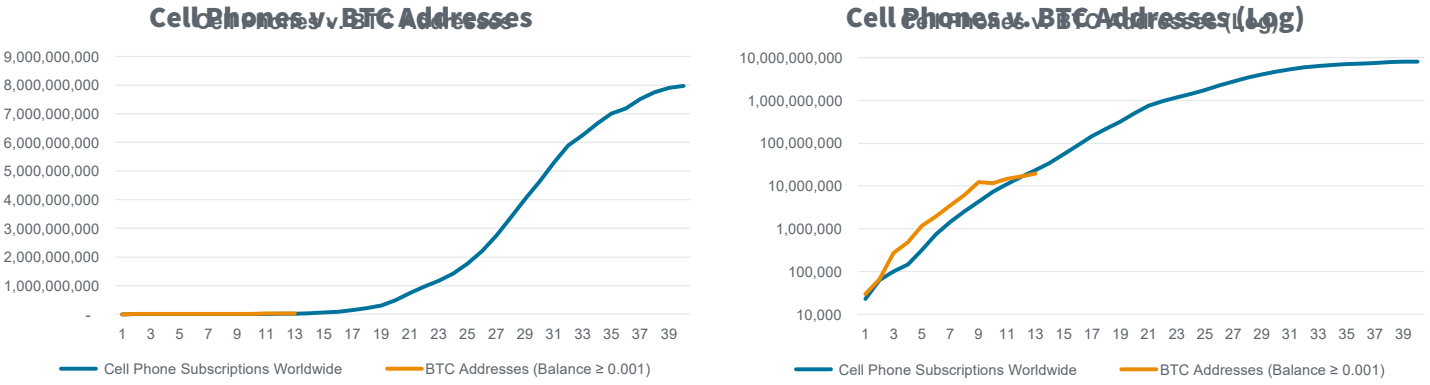
Adoption Curves in Real Life

The speed and size of adoption for any given technology can vary and depends on several possible factors related to how much of an improvement the new technology provides relative to its predecessor and the switching costs associated with adopting the newly offered technology. Shown below are estimates for several technological advancements throughout history, each following a similar pattern for their respective adoption.



Data Source: World Bank Data, 05/31/2022.

Cars, toilets, computers, cell phones, and the internet all exhibit similar historical adoption curves – often with slow initial adoption, followed by rapid acceleration and normalization of the new technology.



Data Source: World Bank Economic Data & Coin Metrics, 05/31/2022.

Similarly, bitcoin's address growth, a rough approximation for usage and user growth, displays a similar pattern to these prior technologies. Mobile phone subscribers, internet adoption, and many of these other technological adoption curves look familiar in nature to that of bitcoin's fundamental adoption seen today. This gives a useful proxy for estimating future adoption and a potential framework for which to project value accrual to this monetary network, given the potential Metcalfe's Law relationship.

Modeling Bitcoin using Metcalfe's Law

The observation of bitcoin's adoption and price growth having a Metcalfe's Law-like relationship originated from a 2018 paper written by Timothy Peterson.[9] Peterson wrote, "Our goal is not to offer a comprehensive valuation model in the strictest sense. Rather, we demonstrate how Metcalfe value can be used to evaluate if bitcoin's price is behaving as model factors would predict. We conclude with the finding that Metcalfe's law helps explain bitcoin's price formation."

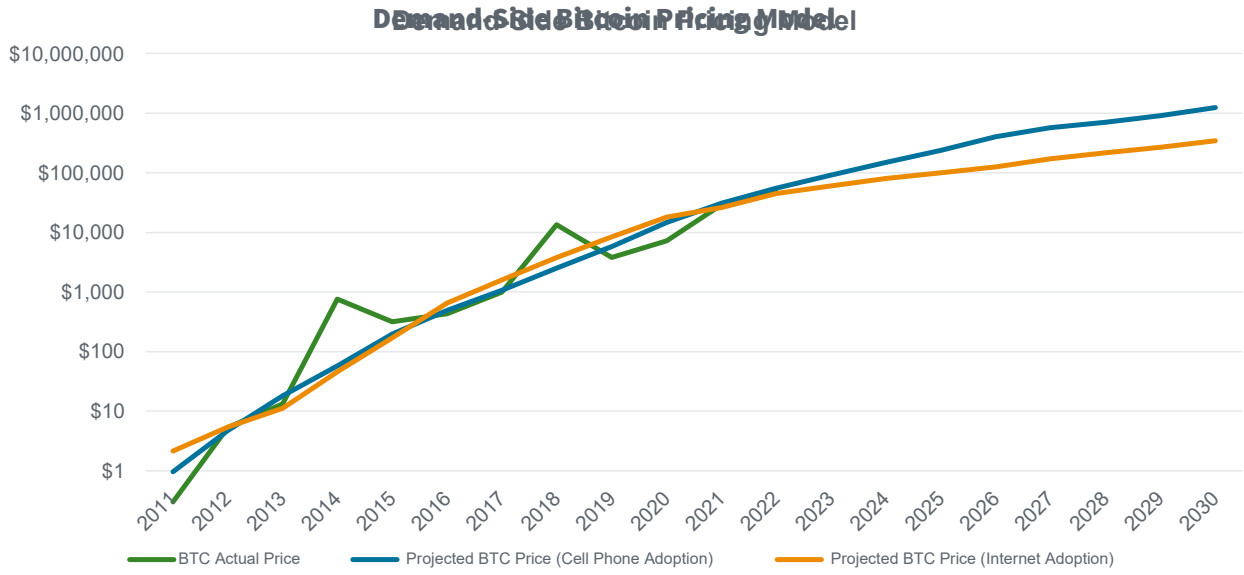
Here, we will attempt to utilize the potential Metcalfe's Law relationship to inform a possible valuation technique based on projected address growth and its linkage to price. Historic adoption curves can be used as the basis for projecting potential future address growth, given bitcoin's adoption curve has progressed similarly to other technology adoption curves.

To best capture this Metcalfe's Law relationship, we employ a power regression model inspired by Lumos Investment's Director of Global Macro, Jurrien Timmer. The model is relatively simple consisting of just three main steps:

1. Project bitcoin's network (address) growth using historical technology adoption curves
2. Regress bitcoin's price against its actual historical network growth
3. Project bitcoin's price using the projected address growth curve from step 1

9 https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3078248

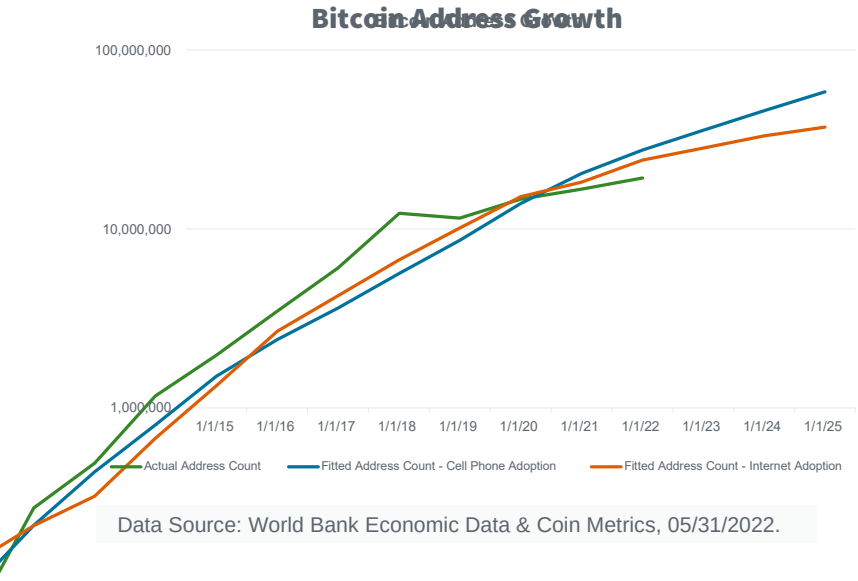
We use two future growth curves based on the adoption of cell phones and the internet. Address count includes wallets with greater than or equal to 0.001 BTC to represent adoption, but the data yields similar results for other wallet count metrics. Dates represent the start of each calendar year.



	2022	2023	2024	2025	2030
Cell Phone Adoption	$55,845	$91,757	$149,244	$239,578	$1,246,088
Internet Adoption	$44,436	$60,070	$80,489	$100,229	$343,186

Data Source: World Bank Economic Data & Coin Metrics, 05/31/2022.

The two adoption curves vary and therefore result in widely different current and future value projections for the price of bitcoin. Additionally, at the time of this writing, the models imply a price higher than that of bitcoin's price today. A closer analysis of the data may reveal why.

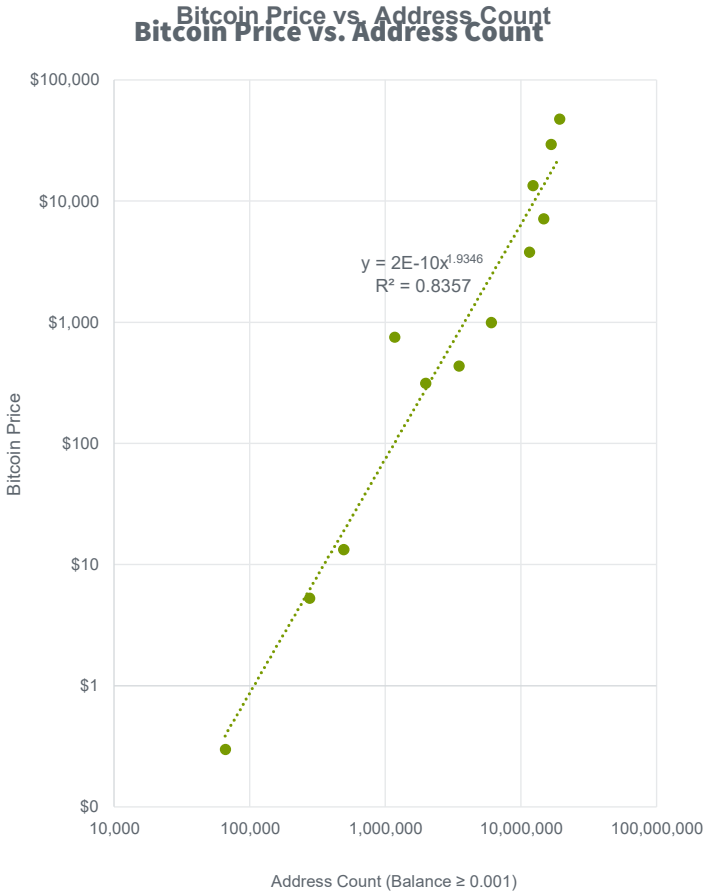


	Actual Address Count - ≥ 0.001 BTC	Fitted Address Count - Cell Phone Adoption	Fitted Address Count - Internet Adoption
01/01/2015	1,976,527	1,503,000	1,331,705
01/01/2016	3,480,928	2,410,571	2,692,127
01/01/2017	6,057,633	3,621,636	4,258,443
01/01/2018	12,252,748	5,623,816	6,721,199
01/01/2019	11,537,760	8,653,647	10,157,939
01/01/2020	14,656,738	13,898,118	15,112,024
01/01/2021	16,688,145	20,446,568	18,283,306
01/01/2022	19,248,990	27,605,605	24,274,019
01/01/2023		35,651,644	28,403,670
01/01/2024		45,803,430	33,082,941

Data Source: World Bank Economic Data & Coin Metrics, 05/31/2022.

Bitcoin's address growth rate has tapered over the past two years, shown above, leading to an address count that is below that of both model projections. This is likely a contributing factor for why the price of bitcoin is trading below both models today, given that the relationship of Metcalfe's Law is between adoption, measured here via address count growth, and price. The internet adoption model, a tamer growth rate with more conservative price expectations, may make for a more realistic growth trajectory for the adoption and price of bitcoin, seeing that the growth rate associated with the cell phone adoption model is far more aggressive in recent and future years.

Relying solely on the address count at the time of this writing and leaving aside projections for future address growth, we can apply the historical relationship between price and address count to derive an implied fair value. As of this writing on May 31, 2022, the number of addresses with greater than 0.001 bitcoin is equal to 20,533,359 according to Coin Metrics. Using the historical relationship between address count and bitcoin price, in conjunction with the current number of outstanding bitcoin addresses, we receive a modeled bitcoin price of $28,036, which is just below that of today's price around $30,000. Note that this does not capture future address growth expectations, and hence why applying historical adoption curves could be useful.



Data Source: Coin Metrics, 05/31/2022.

It becomes obvious just how sensitive modeling the value of a network like bitcoin is to the future rate of growth in its demand. It is clear across each of these adoption curves that long-term adoption could be a driving force for the price of bitcoin, even though precise valuation using this method is heavily dependent on the implied future rate of adoption. Estimating future network demand and adoption, via metrics such as address count growth, will be important to monitoring the future growth in demand for bitcoin and potentially imputing an approximation of the assets fair value.

Limitations to Metcalfe's Law Modeling

There are no models that come without potential flaws and assumptions that can lead to an increased margin for error. Modeling the price of bitcoin using the demand curve is no exception. Here are a few key assumptions made by attempting to model bitcoin using address growth to represent adoption:

1. **Address growth implies user adoption**: Single users can have multiple addresses, and multiple users can be represented by one omnibus custodial address. Still, increased address usage is a sign of overall increased network usage, but not in a perfect 1-for-1 manner.

2. **Addresses have equal weight regardless of the dollar amount**: Wealthier individuals or capital allocators choosing to adopt bitcoin have a larger impact on price than smaller individuals opting into the network. This is not effectively captured via Metcalfe's Law through address growth.

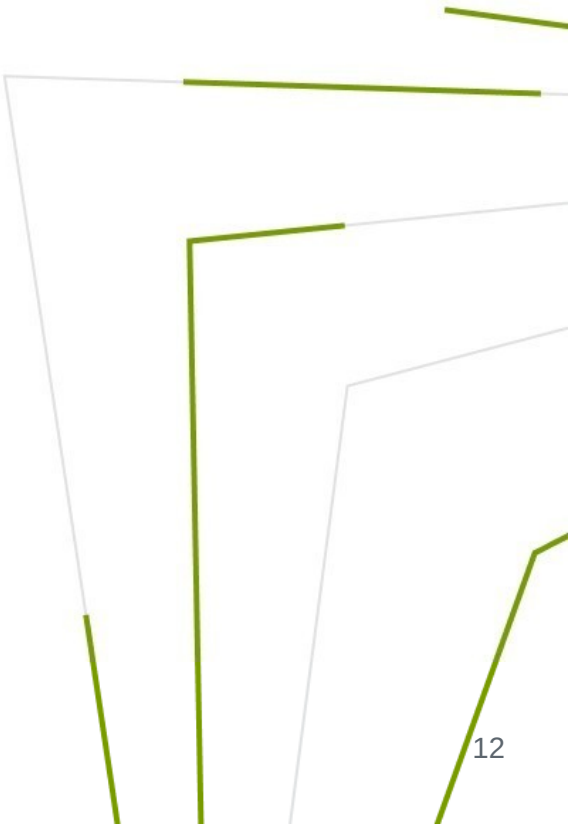
3. **Adoption will continue in a similar fashion as prior technology adoption curves**: Bitcoin's historic network adoption looks similar to the technological adoption curves discussed previously in this piece. However, in recent years this address count growth has not accelerated at the same pace as the two models would imply.

Conclusion

> "All Models Are Wrong, But Some Are Useful"
> - George Box, British Statistician

Modeling bitcoin based on a growing demand curve, though clearly sensitive to the assumed forward adoption rate, shows that an asset with a predetermined supply schedule and an adoption curve that is assumed to replicate prior technologies has only one corrective factor — price. If individuals continue to interact with and store value on the bitcoin network, shown in this paper via increased address count, then the laws of growing network effects imply that the network's value will increase at an exponential rate relative to the increase in adoption.

Models used to predict future outcomes will always suffer from imperfections, but creating a valuation framework and understanding the assumptions embedded within it can help inform better investment decision making. For bitcoin, a path to fulfilling the title of "digital gold" could be in store if its demand curve follows a similar path of prior technologies.



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