The Network Effect

Why Digital Currency Has Value

CANE ISLAND
DIGITAL RESEARCH

SEPTEMBER 2019

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September 2019

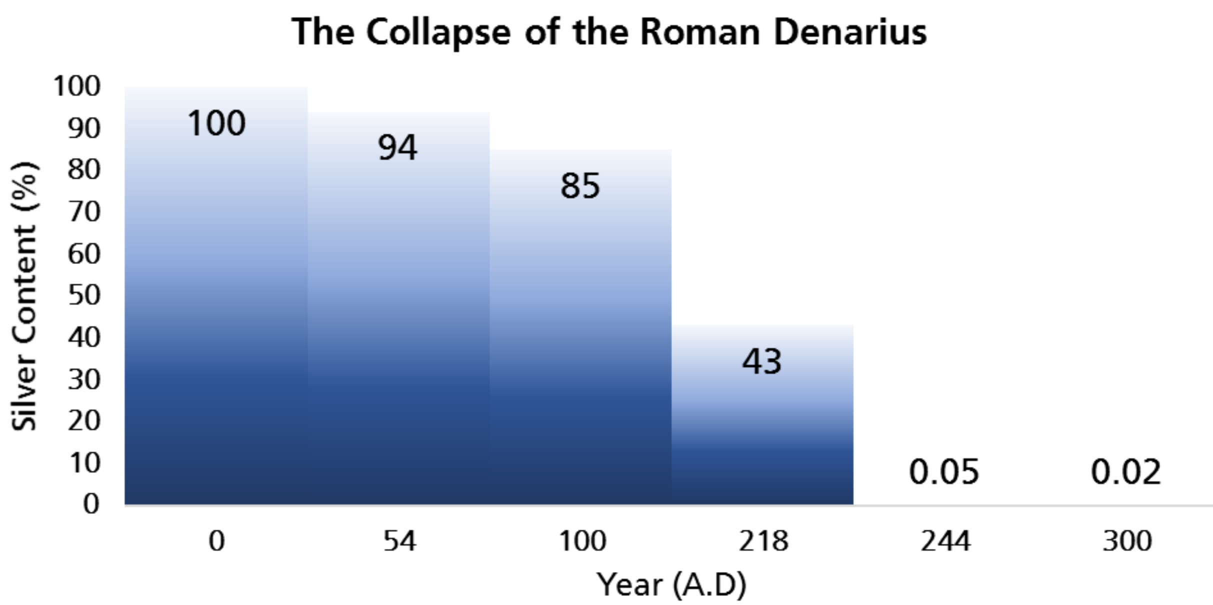
Cryptocurrency and network economics are areas which are unfamiliar to many. However, there is a mathematical principle known as Metcalfe's Law which explains why cryptocurrency has value.

Is Cryptocurrency Real Money?

There are two types of money: commodity money and representative money.

Commodity money is traditionally found in gold and silver coins. Gold and silver are suitable for coinage because they do not decay, rot, or rust; were malleable and divisible into smaller parts (such as gold "pieces of eight"); and were rare and not able to be counterfeited. Gold and silver have been used as money for 2,500 years.

The risk with commodity money is debasement. This involves reducing the quantity of gold or silver in a coin without changing its face value. The Roman Empire substantially devalued its currency by debasement. By 300 A.D., the once invincible Roman Denarius was no longer accepted as currency by the public.

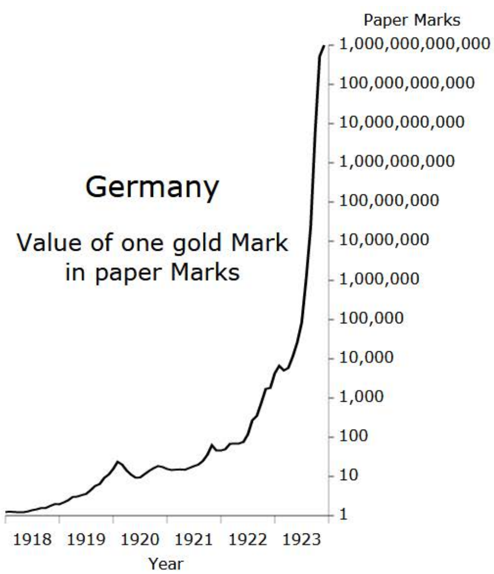


The origin of the word "Eurerka!" (Greek: "I found it!") is attributed to Archimedes, who, while bathing, discovered a method for determining the purity of gold objects by water displacement. This method would be used for centuries to ascertain the validity of commodity money.

Representative money is money that does not have intrinsic value itself, but can be exchanged for things that do have intrinsic value. There are two types of representative money: fiat money and fiduciary money.

Fiat money is money that has a stated value by decree of a government. It is legal currency and only has value because the issuing authority says so. Nearly all money in the world, including coins and banknotes, is fiat money. The U.S. dollar has been pure fiat money for less than 50 years.

The primary problem with fiat money is the risk of inflation, which is caused by issuing more money. Since it costs almost nothing to make fiat money, the temptation to use it to pay the public debt is overwhelming. Modern examples include German Marks post-WWI, and Venezuela's Bolivar today. In 1918, a German Reichsmark was worth one gold mark. Five years later, it would take 1 trillion Reichsmarks to exchange for one gold mark.



In 2005, the Venezuelan Bolivar was worth about 40 U.S. cents. In early 2018, one Venezeulan Bolivar was worth about 10 cents. By August 2018, it took almost 2.5 million Bolivars to buy one U.S. dollar.

Fiduciary money has value only because parties engaging in exchange agree on its value. You have been using fiduciary money for most of your life. It includes things like frequent flyer points, transit cards and tokens, even grocery coupons. Cryptocurrency is fiduciary money because the users agree on its value.

A great example of fiduciary money involves a once-popular Italian telephone token–the *gettone*.

The word *gettone* (pronounced "jet-TONE-ay", plural: *gettoni*) literally means "token." The first Italian telephone token was created in 1927. It was a little disc made of an alloy of copper, nickel and zinc, or bronze. Production stopped in 1983 when it was replaced with magnetic phone cards. It is estimated that 600 million such tokens were produced.

Gettoni were commonly used as and interchangeable with a 50 Lira coin until 1980, when its value (and the cost of a phone call) suddenly doubled to 100 Lira. The doubling occurred again in 1984, to 200 Lira, again a result of a price increase associated with pay-phone calls. It remained at that value until 2001, when the Euro was introduced and the *gettone* suddenly lost its money-like nature in the Italian economy.

The parallels between the *gettone* and cryptocurrency are many. Both serve only limited roles as a literal form of currency, and as fiduciary money both are intrinsically worthless. It was not necessary to have a *gettone* to make a phone call; one could use a phone at the home or office to do that. Likewise, one is not required to use cryptocurrency to make purchases, but can choose to do so for convenience or other reasons. People carried both *gettoni* and Lira, in the same way people hold cryptocurrency and sovereign fiat money. Like cryptocurrency, the cost to counterfeit a *gettone*, relative to its value as a medium of exchange, was so high it was ridiculous to even consider it. And, like cryptocurrency, a user could do one of three things: spend it, exchange it for government currency, or hold it.

A No-Nonsense Explanation of Blockchain

The problem with digital currency is that it can be easily copied and counterfeited. The inventor of bitcoin, Satoshi Nakamoto[1], came up with an ingenious solution to what is known as the "double spend" problem: give everyone who so desires a copy of the transaction ledger. While it is relatively simple to "cook the books" on a single ledger, it is nearly impossible to alter hundreds or thousands of ledgers, especially if those ledgers are dispersed in a variety of locations. So long as there is a means of comparing multiple, distributed ledgers, the system itself provides the trust in ledger integrity.

Also, it is not necessary to compare all ledgers to each other. One need only compare a few ledgers to get a high degree of confidence that the subject ledger is legitimate. With two ledgers one can make one comparison. With four ledgers, it is possible to make six comparison. With six ledgers, it is possible to make 15 comparisons. It takes fewer than 50 ledgers to make a possible 1,000 comparisons! This relationship is known as Metcalfe's law and is discussed later.

Providing everyone a copy of the transaction ledger poses a major problem. Would you want your bank history in the hands of anyone and everyone? The information would need to be encrypted, and done so in a way that would be virtually impossible to break or hack. To accomplish this, Nakamoto invented the blockchain.

How is this different from a traditional encrypted ledger?

[1] Satoshi Nakamoto is believed to be a pseudonym. In our research, we have concluded that Nakamoto represents at least two individuals who collaborated on the project, both of whom are now deceased.

Here is a sample ledger that has been encrypted using traditional means:[2] Although it looks complicated, experts would be able to crack this code in a reasonable time.

Transaction		**Encoded Transaction**
$10 from Bob to Jane	→	$10 ybwd jhl bf rtxm
$5 from Jane to Mary	→	$5 ybwd rtxm kw fkzp
$14 from Suresh to Mark	→	$14 ybwd anbmjp my urzd

With blockchain encryption, there are several layers of encryption, including encryption within encryption. Specifically, the previous encrypted record is included as part of the next record. This "nesting doll" effect makes it impossible to change only one record.

In the example below, we take the encoded transaction and add an encoded portion of the previous transaction (called a hash). This links the records together in a chain of encrypted records.

Transaction		Encoded Transaction		Hash from previous		Stored Record
$10 from Bob to Jane	→	$10 ybwd jhl bf rtxm	+	9f10893b4a54a05790059b4e2c089065	=	92b8c1fc1aea3d5a89f8ca001204d952
$5 from Jane to Mary	→	$5 ybwd rtxm kw fkzp	+	92b8c1fc1aea3d5a89f8ca001204d952	=	97aaf953dac1094b07d769b4258af5b0
$14 from Suresh to Mark	→	$14 ybwd anbmjp my urzd	+	97aaf953dac1094b07d769b4258af5b0	=	631da6403fcc63b84e279af00086a595

The actual encryption and blockchain implementation for cryptocurrencies is more robust than this relatively simple example. Most use public key encryption technology. Public keys may be disseminated widely, and private keys which are known only to the owner. This accomplishes two functions: authentication, where the public key verifies that a holder of the paired private key sent the message, and encryption, where only the paired private key holder can decrypt the message encrypted with the public key.

To validate that a transaction, one just needs a public key and the previous stored record, which is also public. This approach also permits viewing the transaction ledger amounts, while preserving a degree of privacy (some would say anonymity) about the parties to the transaction.

As blockchains are shared and everyone can see what is on the blockchain, this allows the system to be transparent and as a result trust is established.

Blockchain is simple and cheap to implement. Nakamoto provided his blockchain code in full when Bitcoin was developed. Any first-year university computer science student can build a blockchain application.

Blockchain allows the quicker settlement of transactions as it does not require a lengthy process of verification, reconciliation, and clearance because a single version of agreed upon data is already available on a shared ledger between financial organizations. No third party or clearing houses are required in the blockchain model, this can massively eliminate overhead costs in the form of fees that are paid to clearing houses or trusted third parties.

[2] For cryptologists, this was encoded using a Vigenere cypher with a random key.

Metcalfe's Law and The Network Effect

The *gettone* analogy above is important because Metcalfe's law, upon which our work is based, originated from a description of telephone networks. The holders of *gettoni* and the payphones themselves are a network. The value of a *gettone* to someone in that network, when spending the coin, is one of convenience and the value of the information relayed over the network. If we assume a growing number of pay telephones and callers, and then apply the constraint of a limited number of *gettoni*, we have mirrored the key elements of cryptocurrency's supply and demand characteristics.

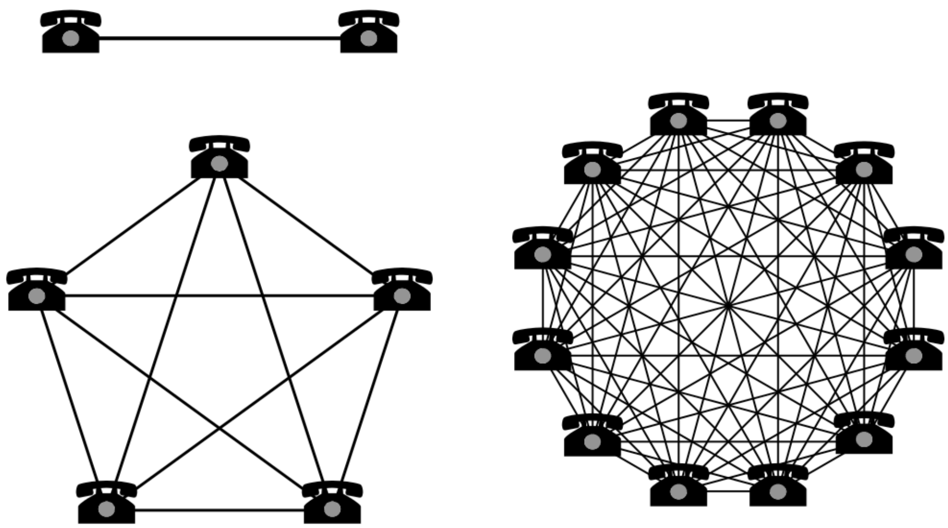
Network economics is a new field, and so much of the economics around cryptocurrency is foreign to most. The network economy is the emerging economic order within the information society. The name stems from a key attribute−products and services are created and value is added through social networks operating on large or global scales. This is in sharp contrast to industrial-era economies, in which ownership of physical or intellectual property stems from its development by a single enterprise. Examples of network effects can be found in internet websites, mobile phone proliferation, and social media applications like Facebook, Twitter, LinkedIn, SnapChat, and Instagram.

Metcalfe's Law is regarded as the first and most reliable explanation of the network effect.[3] It is a calculation of the maximum number of connections a network can make, based on the number of nodes (or users). The value of any network, be it currency, internet, telephone, or social, is dependent upon the number of users. Here is an example of the calculation:

> "If only one person has a telephone, then the device is obviously quite useless. If two people have telephones, it is possible to make one connection between two people. As the number of people (*n*) rises in a linear fashion, the number of possible connections increases exponentially. Thus, if 5 people have telephones, letting **n** in the equation equal 5 will produce 10 possible connections. If *n* were equal to 10, there would be 45 possible connections. In other words, a doubling of *n*, or a doubling of the nodes so to speak, increases the number of possible connections by a factor of 4.5. If one then further increases the number *n* to 12, the number of possible connections

[3] Reed E. Hundt, then the chairman of the U.S. Federal Communications Commission, declared that Metcalfe's Law and Moore's Law "give us the best foundation for understanding the Internet." Marc Andreessen, who created the first popular Web browser and went on to cofound Netscape, attributed the rapid development of the Web—for example, the growth in AOL's subscriber base—to Metcalfe's Law.

increases to 66. Hence, a 20% increase in *n* produces a 46.67% increase in possible connections."[4]



Two telephones can make only one connection, five can make ten connections, and twelve can make 66 connections.

In 2017, we performed a comparison of Facebook's growth to that of Bitcoin. Facebook is uniquely suited for comparative study because it shares with Bitcoin many similar circumstances:

- Both have characteristics of networks.
- Both have observable market values.
- Both have observable values for nodes (wallets and accounts).
- Both had nearly identical early growth rates, averaging 100% per year (doubling).
- Both were banned in China.
- Facebook was the subject for proof of Metcalfe's law in two papers.
- At the time, Bitcoin was 8 years into existence; Facebook IPO'd in its 8th year.

Facebook, for its first 8 years, did not have an observable market value. But using data on the number of accounts, we can derive the value from Metcalfe's law. Likewise, we can derive a value for Bitcoin from a projected growth rate and apply Metcalfe's law. We can also compare Facebook's actual market capitalization to the value predicted by Metcalfe's law.

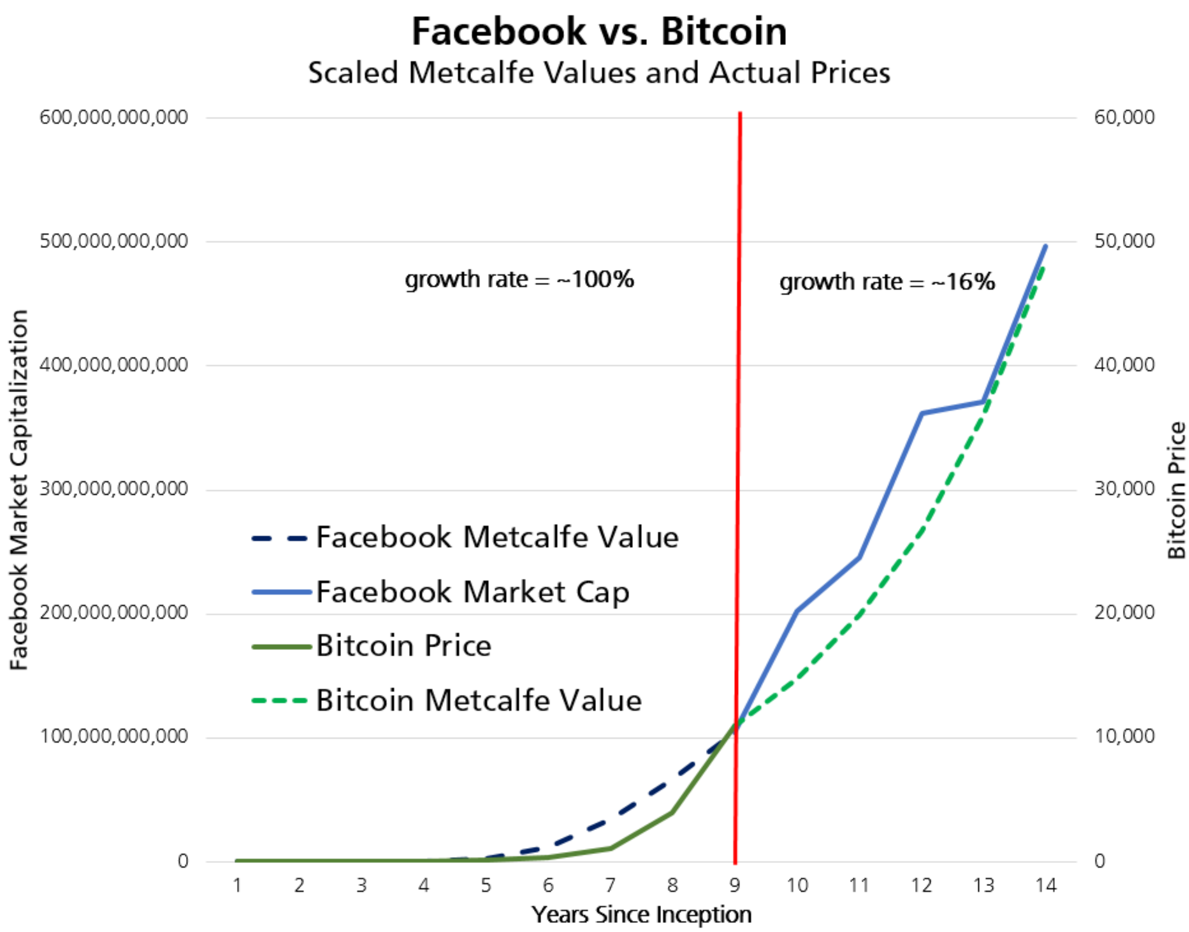
Both Facebook and Bitcoin doubled the number of network nodes (user accounts and wallets) early on. Since its initial public offering, Facebook has grown its users at a rate of about 16% per year. Using Metcalfe's law, we can impute a value for Facebook pre-IPO using actual users.[5] Using

[4] From the FRMO Corporation Annual Meeting of Shareholders, September 15, 2017.
[5] These Metcalfe values have been scaled by a coefficient so as to better visually align with the subject price/market capitalization under scrutiny. The underlying Metcalfe value itself is not modified, it is only adjusted by an order of magnitude.

Facebook's post-IPO growth rate of 16%, and Metcalfe's law, we projected a value for Bitcoin going forward.

$$\mathrm{C} \times n = \mathrm{A} \times \frac{\mathrm{n}(\mathrm{n}-1)}{2}$$

Metcalfe's Law



People could not claim Facebook was in a bubble in its early years because, unlike Bitcoin, its market value was not visible. Had Facebook users been co-owners of the company, they would have experienced Bitcoin-like returns. However, its early growth rate in user accounts of 100% was not sustainable in the long run. Likewise, Bitcoin's adoption-stage growth rate of 100% is also not sustainable.

We don't know what Bitcoin's future annual growth rate will be, but 16% is not unreasonable. If Bitcoin ceased is supernormal growth today, and grew at 16% for the next five years, a reasonable expectation of return based on Metcalfe value would be just over 50% per year. By comparison, Facebook's post-IPO growth in market cap was 31% per year.

Interestingly, the size of a network determines its value, even if nothing is exchanged! Suppose you have tickets to see a Screaming Lord Byron concert next Thursday night. You can't go, so you offer the tickets to five of your friends for $100 each. Nobody accepts your offer. What can we conclude?

Not much. Perhaps they are busy that night. Or perhaps they don't like Screaming Lord Byron. Or maybe the price is too high.

So you post the tickets on an ticket exchange website, where a thousand people view your advertisement. Still, nobody buys the tickets from you. Now what can we conclude? It's unlikely that so many concert-goers would be busy and pass up a concert to see Screaming Lord Byron. It's obvious the price is too high. But also, a thousand people viewed that ad and saw that nobody else had purchased the tickets. This confirms their own assessment that the price was too high, and their decision to not buy was correct.

Many are familiar with the real estate statistic that shows "days listed" for property sales. The longer the property is listed, the less attraction it gathers. Without even visiting the property, a prospective buyer can suspect that either the price is too high or the condition too poor for the price. Buyers and sellers in financial markets receive important information–information that pertains directly to the thing in a potential transaction–and this imparts value to the network of users.

There is one glaring problem with an analysis that only considers number of users: the value of networks cannot go up forever. An incomplete application Metcalfe's law measures only the potential number of contacts, i.e., the technological side of a network. However the utility of a network depends upon the number of nodes actually in contact (transactions) and the quality of information transacted. Metcalfe said that, over time, this utility declines. In other words, the effect of growth in users on value is subject to the Law of Diminishing Marginal Returns.

Practical examples of this degradation in network value include things like spam, excessive advertising, and other bits of false, irrelevant, or uninteresting pieces of information.

Imagine you throw a party. Only a few people show up, and it's pretty boring. There is lots of opportunity to interact with the people who are there, but there just isn't a lot of potential for interaction in general. As more people show up, the party gets better. But then consider a party where too many people show up. It's too crowded, you can't hold a conversation. Most people are strangers and some behave badly. Drinks are spilling everywhere. It's so crowded, people can't move around or dance. This is an example of diminishing marginal returns. We call this the Goldilocks effect: the network cannot be too big or too small, it must be just right to maximize value.

Metcalfe expressed this concept in his formula with a term he called "Affinity," dimensioned as value-per-user, and labeled as A in his equation. As n goes up, A goes down. This puts a limit on the network effect.

In our experience, most cryptocurrency models do not account for diminishing marginal returns. As a result, they generate values that are too high for cryptocurrency.

To date we have been able to use Metcalfe's law to explain prices in dozens of cryptocurrencies. We believe Metcalfe's Law explains a large number of economic and financial phenomenon. These include social media applications like Facebook and LinkedIn; payment systems like PayPal and Square; and mobile phone companies like Apple, Samsung, and Google. We also believe that Metcalfe's law has been a predominant factor in the most successful economies throughout history:

- The Roman Empire with its armies and network of roads;
- The British Empire with its navy and network of shipping routes; and

- The United States with the use of transcontinental rail, telegraph and telephone; electrical grids; interstate highway; air transport; internet; and communications satellites.

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