An Equilibrium Crypto-Token Valuation Model

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Abstract
We discuss the value of native currencies on a blockchain and present a supply-demand equilibrium framework for valuing crypto-tokens.

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Contents

1. Introduction

Cryptocurrency valuation has becoming increasingly important for investors and also firms considering coin offerings as a way of raising capital. Valuation is an integral part of tokenomics, aiding to better token design. More than 19 billion has been raised over the last four years. However, a recent study by ICO advisory firm Satis Group find that over 80% of ICOs issued in 2017 were scams. A TechCrunch article using data from Coinopsy and DeadCoins found that as of June 30, 2018, more than 1,000 crypto projects are already dead. There is no doubt there are high levels of uncertainty and information asymmetry in ICO markets. This in turn can lead to a dysfunctional market.

In light of this, how does an investor distinguish between scams and legitimate value generating businesses? How does a firm conducting an ICO signal to the market that it is a not a scam?

Better valuation techniques plays a central role in functioning markets. Firms conducting ICOs that can provide robust and transparent valuation models justifying its token price, show stronger signal to potential investors in a market where scams are prevalent. Similarly, if investors are also armed with better tools for valuing tokens, they are less likely to fall for scam coins and more likely to ask the right questions. In both cases, information disclosure is improved and information asymmetry is reduced. Therefore, better understanding among market participants on crypto-token valuation is integral for a well functioning market.

To date, there has been no widely accepted approach for valuing crypto-tokens. This is largely because traditional security valuation techniques, such as discounted cash flows, do not easily apply. Ciaian, Rajcaniova and Kancs (2016) [1] examine the quantity theory of money on Bitcoin data. However, Burniske (2017) [2] was first to popularize this technique for crypto-tokens. Peterson (2018) [3] and Van Vliet (2018) [4] focus on the network effect and use Metcalfe's Law for valuing Bitcoin. We discuss the value of native currencies on a blockchain and present a supply-demand equilibrium framework for valuing crypto-tokens.

2. Token Value

2.1 Why do we need them?

Blockchain-based networks introduce native crypto-tokens as the common currency for their ecosystem. This process is defined as 'token embedding' by Cong, Li and Wang (2018) [5]. The central question is *why do we need a native currency in the first place? Why can't users on the network simply use fiat currency, such as USD?* If this question cannot be answered convincingly, then clearly the crypto-token is unlikely to hold any intrinsic value. A well designed token is likely to hold greater value if users are able to appreciate its function within the network.

So why do we need a native currency?

2.1.1 Incentivization

As pointed out in Nakamoto's original whitepaper on Bitcoin, a native currency is used to provide incentive to miners to contribute to the stability of the Bitcoin ecosystem. More generally, if a blockchain is developed without a native currency, then who will be willing to act as validators and partake in decentralized consensus? If participants who contribute in maintaining the blockchain are incentvized in fiat currency, then who would in charge of paying? Very quickly, one realizes some level of centralization would be required. In order to maintain a decentralized system, a native currency is therefore required. This is the only way to align the incentives of the users to the platform.

2.1.2 Convenience Yield

For most tokens, there is no mining. Convenience plays a large role as to why a token is required. When potential users are global, transacting in a common currency is more convenient, and free from foreign exchange transaction costs. For example, it is cheaper to do international payments via the Ripple network than through traditional banks.

2.1.3 Collecting Seigniorage

Through the introduction of native currencies, the issuer is able to collect 'seigniorage' through an ICO, i.e., raising capital. Users are required to hold the tokens issued from an ICO in order to transact in the ecosystem. The capital collected from the ICO is a form of monopoly rent. The more demand the users have in transacting on the blockchain means higher ICO revenues. An ICO is also a good way for early stage ventures to gauge the level of interest in their product.

2.2 Why is there Value?

So, now that we know why native currencies are required in order for a blockchain to function, the next question would be: *why do native currencies hold positive value?*

Arguably, if you want to transact on a blockchain platform with another counterparty, you could exchange dollars for the native currency, and make a transfer on the blockchain, and then immediately your counterparty may exchange the native currency back into dollars. If this process occurs instantaneously, the velocity of the native currency is infinite. Therefore there is no net demand for the native currency and the value is zero. In order for cryptocurrencies to have positive value, the users need to hold the coins, and subsequently slow down the velocity of the native currency. 'Hodlers' play an important role in supporting the value of cryptocurrencies by reducing velocity.

Therefore, the design of the coin plays an important role in influencing the velocity of the coin and subsequently its value. Below are a few design features that impact coin velocity.

2.2.1 Staking tokens

Staking tokens or work tokens are a design feature that creates demand for holding coins, as decentralized miners and service providers are required to hold the coin in order to earn the right to serve the system (Proof-of-Stake). This in turn slows down the velocity of the coin and increases its value. In the recent Filecoin ICO, service providers are required to escrow a certain number of Filecoin tokens. These coins are stored and used as collateral if they fail to deliver the service.

2.2.2 Collateral

Smart contracts also require a certain amount of native currencies to be escrowed. The fact that users hold cryptocurrency tokens as collateral slows down its velocity and subsequently increases its value.

2.2.3 Confirmation time

The process for validating transactions with decentralized consensus requires more time centralized systems. During the confirmation time, the cryptocurrency cannot be liquidated, thus reducing velocity.

3. Valuation Method

3.1 An Equilibrium Model

Assume there is a platform where tokens are the only accepted medium of exchange. Let this platform be designed to provide the purchase and sales of a specific service or product. We assume this service or product must have a value ascribed to it in the fiat economy. Therefore, demand for this service in terms of price in USD can be expressed in a linear fashion as,

$$Q^D = \gamma(V^D - P^{USD})_+ \tag{1}$$

where,

- Q^D is the quantity (units of service) demanded by the market
- $\gamma > 0$ is an inverse risk aversion coefficient (or a measure of 'appetite' for the service)
- V^D is the maximum value in USD market participants are willing to pay for the a unit of service
- P^{USD} is the price in USD of a unit of service

This is intuitive as demand is positive as long as the customer's valuation for the service is greater than the price, $V^D > P^{USD}$. Let us also assume the supplier(s) on this platform, are willing to supply according to,

$$Q^S = \delta(P^{USD} - V^S)_+ \tag{2}$$

where,

- Q^S is the quantity (units of service) supplied by the market
- $\delta > 0$ is the supplier's 'appetite' to expand service
- V^S is the minimum value in USD for there to be a willing supplier to sell on the platform

The market clearing condition is $Q^S = Q^D$, i.e., the quantity supplied equates to the quantity demanded. Therefore the optimal price of the service at equilibrium is $P^* = (\gamma V^D + \delta V^S)/(\gamma + \delta)$ and the optimal quantity is $Q^* = \gamma\delta(V^D - V^S)/(\gamma + \delta)$.

So far we have not incorporated any tokens into this model. We have simply determined the optimal price in USD and quantity sold for the service on the platform. This is important in gauging the scale of the platform. However, trade on this platform can only be conducted in tokens, not USD. Therefore, we need to amend our demand and supply functions to reflect a relationship between quantity and token price (not USD price).

Let us introduce P^{TOKEN} to be the price in tokens of a unit of service. And let us also introduce X to be the exchange rate for tokens to 1 USD. Thus, $1/X$ is the price of a token in USD. This is ultimately what we want to solve. The modified demand and supply equations are,

$$Q^D = \frac{\gamma}{X}(V^D X - P^{TOKEN})_+ \tag{3}$$

$$Q^S = \frac{\delta}{X}(P^{TOKEN} - V^S X)_+ \tag{4}$$

From $Q^D = Q^S$, we get equilibrium price (the number of tokens required for the service) and quantity (units of service demanded),

$$P^{TOKEN*} = \frac{(\gamma V^D + \delta V^S)X}{\gamma + \delta}$$

$$Q^* = \frac{\gamma\delta(V^D - V^S)}{\gamma + \delta}$$

Note the optimal quantity is not related to X, i.e., the value of the token does not impact the supply of the underlying product. Next we turn to the Quantity Theory of Money equation, which is popular among crypto-investors for estimating price. It is expressed as,

$$Mv = PQ \tag{5}$$

we point out that to apply it to the crypto-token ecosystem the unit of exchange here is the token, i.e., M denotes money supply in tokens (not USD) and similarly, P denotes the price of a transaction in tokens. Q denotes the number of transactions and v denotes the velocity of the token. We substitute P and Q for our optimal P^{TOKEN*} and Q^* and solve for X.

$$Mv = \frac{(\gamma V^D + \delta V^S)X}{\gamma + \delta} \frac{\gamma\delta(V^D - V^S)}{\gamma + \delta}$$

and thus,

$$X = \frac{Mv(\gamma + \delta)^2}{\gamma\delta(V^D - V^S)(\gamma V^D + \delta V^S)} \tag{6}$$

The equilibrium price of a token in USD would therefore be $1/X$. Thus,

$$\text{Token Value} = \frac{\gamma\delta(V^D - V^S)(\gamma V^D + \delta V^S)}{Mv(\gamma + \delta)^2}$$

We note a few simple relationships:

1. Increasing money supply $\uparrow M \rightarrow \uparrow X$ and thus reduces token value in USD.
2. Increasing token velocity $\uparrow v \rightarrow \uparrow X$ and thus reduces token value in USD.
3. Increasing spread between the max demand and min cost of the service, $\uparrow (V^D - V^S) \rightarrow \downarrow X$ and thus increases token value in USD.

Differentiating with respect to γ (demand appetite),

$$\frac{\partial X}{\partial \gamma} = \frac{Mv\delta(\gamma + \delta)}{\gamma^2\delta(V^D - V^S)(\gamma V^D + \delta V^S)^2} \times (V^S(\gamma - \delta) - 2\gamma V^D) \tag{7}$$

Since $V^D > V^S$ and $2\gamma > \gamma - \delta$, we can see that $\frac{\partial X^2}{\partial \gamma} < 0$, and thus $\uparrow \gamma \rightarrow \downarrow X$ and an increase in token value in USD.

Similarly, when differentiating with respect to δ (supplier appetite to expand),

$$\frac{\partial X}{\partial \delta} = \frac{Mv\gamma(\gamma + \delta)}{\gamma\delta^2(V^D - V^S)(\gamma V^D + \delta V^S)^2} \times (V^D(\delta - \gamma) - 2\delta V^S) \tag{8}$$

Here if $\delta < \gamma$, then $\frac{\partial X^2}{\partial \gamma} < 0$, however if $\delta > \gamma$ it is possible that an increased supplier appetite will reduce token price in USD. The relationship is not entirely clear. In fiat equilibrium, when δ increases, we expect a decrease in equilibrium price. Here, token value in USD can actually increase, because at the same time, the number of tokens required to purchase a unit of service decreases.

3.2 A Fixed Supply Model

In a platform where we have a single supplier issuing tokens, it may be the case that supply is inelastic. For instance a hotel venture is issuing tokens for exclusive use of their hotel suites. In this case, supply is relatively fixed. Our token demand and supply equations would therefore be,

$$Q^D = \frac{\gamma}{X}(V^D X - P^{TOKEN})_+$$

$$Q^S = Q$$

And therefore, the equilibrium price is

$$P^{TOKEN*} = (V^D - \frac{Q}{\gamma})X \tag{9}$$

Substituting this into the quantity of money equation $Mv = PQ$, we can solve for the exchange rate.

$$X = \frac{Mv\gamma}{Q(\gamma V^D - Q)} \tag{10}$$

We note $\gamma V^D - Q > 0$. Token value is simply $1/X = (V^D - Q/\gamma)\frac{Q}{Mv}$.

We can also see that demand appetite γ is positively related to token value in USD because,

$$\frac{\partial X}{\partial \gamma} = -\frac{Mv}{(\gamma V^D - Q)^2} < 0$$

Let us motivate our models with some examples.

3.3 Example A: CoffeeToken

Let us assume there a new blockchain platform for the buying and selling of a homogeneous product, coffee. CoffeeToken is the only medium used to buy coffee from vendors (suppliers) subscribed to this platform. Once a supplier is subscribed, he or she can only accept CoffeeToken and no longer fiat currency for business.

So how do we design and value CoffeeTokens?

3.3.1 Supply and Demand in USD

The first step is working out the demand and supply of coffee in our town where CoffeeToken plans to operate. Say it is a small town, and thus demand for coffee is estimated to be,

$$Q^D = 200(5 - P^{USD})$$

Therefore, if the price of coffee exceeds \$5, no one is keen on buying coffee. If the coffee was free, the maximum demand for coffee is 1,000 a day (There are constraints such as the population of the town in which CoffeeToken operates). Let the supply for coffee be,

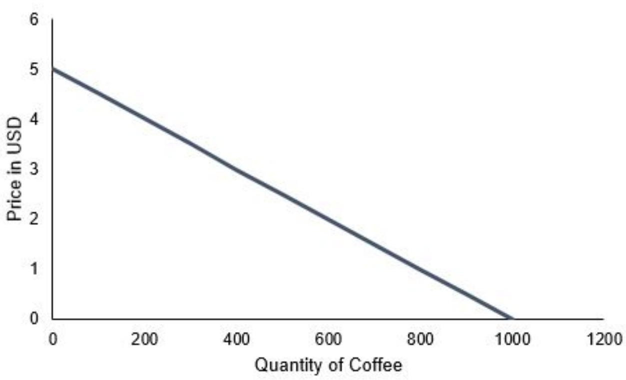

Figure 1. Demand for Coffee in USD

$$Q^S = 200(P^{USD} - 1)$$

Figure 2 shows the equilibrium price for coffee is \$3 and the daily quantity supplied is 400 cups. Therefore, total revenue in this market is \$1,200. The optimal quantity of 400 is unaffected by token design, it is driven by suppliers and customers of coffee and we assume here that blockchain technology and crypto-tokens do not impact consumer spending or supplier marginal cost.

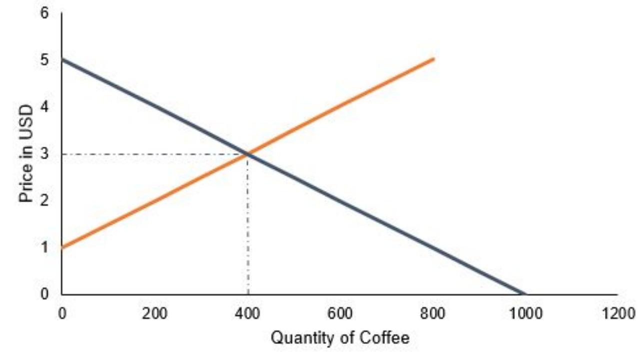

Figure 2. Demand and Supply for Coffee in USD

3.3.2 Supply and Demand in Tokens

We can convert supply and demand functions to be in terms of tokens. The demand function would be,

$$Q^D = \frac{200}{X}(5X - P^{TOKEN})$$

where X is the number of tokens per 1 USD (exchange rate). The supply function would be,

$$Q^S = \frac{200}{X}(P^{TOKEN} - X)$$

In Figure 3, the three equilibrium points A, B and C reflect X at 1.2, 1 and 0.8 respectively. The results are uninteresting, as it simply suggests the equilibrium price of a unit of service in tokens is conditional on the exchange rate of the token. The equilibrium price in USD is maintained at \$3.

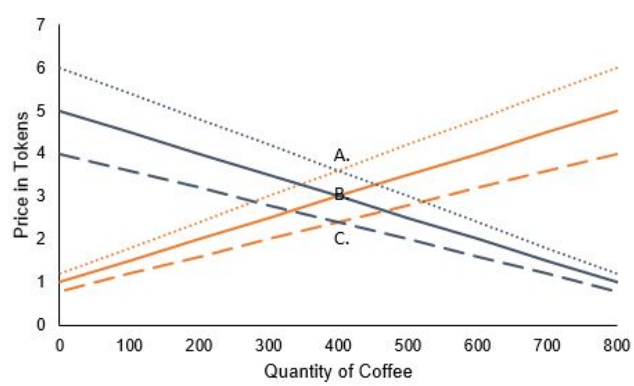

Figure 3. Demand and Supply for Coffee in Tokens

3.3.3 Token Value

To recap our parameters so far, we have the following assumptions in our setup.

1. $\gamma = 200$
2. $\delta = 200$
3. $V^D = 5$
4. $V^S = 1$

We have estimated that the revenue of our platform is \$1,200 and we expect sales of 400 coffees.

Now, lets introduce CoffeeTokens. Lets make the assumption that each token gets used only once per day, i.e. a token velocity of 1. So how many tokens do we need? Lets say we create 400 tokens because we expect 400 transactions. Therefore with $M = 400$ and $v = 1$, we work out that:

1. $X = 1/3$ (from equation 8)
2. Token value = \$3
3. $P^{TOKEN} = 1$

This is relatively intuitive. At equilibrium we expect 400 daily CoffeeToken transactions. One CoffeeToken is used to purchase a coffee on this platform and there are 400 tokens in circulation. Each token is valued at \$3, which is also the equilibrium price in USD.

However, lets say we created 1,000 tokens instead. With $M = 1000$ and $v = 1$, we work out that:

1. $X = 5/6$ (from equation 8)
2. Token value = \$1.2
3. $P^{TOKEN} = 2.5$

Here with an increase in tokens, the equilibrium value of the token falls to \$1.2 In order for coffee suppliers to maintain the same level of output, we now need 2.5 CoffeeTokens to buy a cup of coffee.

Now suppose there's 1,000 tokens in circulation. But token rules have stipulated that the price of a coffee is 1 CoffeeToken. In order for, $M = 1000$, Token value = \$3 and $P^{TOKEN} = 1$ to be true,

1. $v = 0.4$

i.e., token velocity would need to be slower for the valuation to hold true. This could be achieved by 'hodling' 60% of the tokens. Velocity can also slow down if coffee vendors are slower in trading their tokens for USD after receiving them from customers. This reduces the effective number of tokens in circulation.

Now suppose the CoffeeToken ICO was at a price of \$3 and 1,000,000 tokens were issued. If we assumed a token velocity of 1, token value would be diluted to 0.12 cents because there is simply not enough demand for coffee in our town. If the price of a coffee is to be maintained at 1 CoffeeToken, then the implied token velocity would need to be 0.0004 - which is ridiculous! We, therefore, propose to use implied token velocity as a 'sense-check' in determining if a token is overvalued or undervalued. Implied velocity $\hat{v}$ can be estimated from,

$$\hat{v} = \frac{Q^* \times P^*}{M \times \text{Token Price}}$$

If implied velocity is too low it is a sign that the token price is too high.

3.3.4 Projections

So far, we have shown we can value and assess CoffeeToken under current market conditions. Suppose we expect demand to increase over the next three years, by altering consumers appetite γ,

	Current	Year 1	Year 2	Year 3
γ	200	250	300	350
δ	200			
M	400			
v	1			
V^D	5			
V^S	1			
Token Value	\$3	\$3.58	\$4.08	\$4.51
IRR		0.193	0.166	0.146

Here we revert back to using a monetary supply of 400 CoffeeTokens. Using eqn 8, we can project target token value across time. In this case, its \$3 to \$4.51 at the end of the third year. The annualized internal rate of return (IRR) for holding CoffeeToken for three years is 14.6%.

This is a simplistic analysis. A more sophisticated analysis would incorporate changes in velocity. For instance, hodlers anticipating an increase in CoffeeToken price due to increases in γ would reduce v by hodling. On the other hand, as demand for coffee increases, a CoffeeToken may exchange hands in more than 1 transaction per day, thus increasing v.

3.4 Example B: HotelToken

Next let us examine a venture that plans to operate a hotel. Unlike CoffeeToken, there is only one supplier, the hotel owner, and he/she has a fixed number of suites. Here we employ the inelastic supply model in section 3.2.

Let us assume the hotel opens in 5 years time and the building is approved with 500 suites. Let the supply and demand functions in USD be ($\gamma = 2$ and $V^D = 500$),

$$Q^S = 500$$

$$Q^D = 2(500 - P^{USD})$$

The optimal price is \$250 and the supply is 500.

Using equation 12,

$$\text{Token Price} = (V^D - Q/\gamma)\frac{Q}{Mv} = \frac{125000}{Mv}$$

Therefore the price of the token is inversely related to the number of tokens issued and the velocity of the tokens in circulation. To estimate current price for the tokens, a discount factor d needs to be applied.

$$\text{Current Token Price} = \frac{125000}{Mv} \times (1+d)^{-5}$$

The velocity is $v \leq 1$ because when the customer is occupying the suite, the token is locked up as collateral and out of circulation. If $v = 1$, then the token acts like the key required for the customer to open hotel room. Therefore, the price of the key is simply the equilibrium price of a room, i.e. \$250, and the number of keys must equate to the number of rooms. However, most likely $v < 1$ as the holders of the HotelToken are unlikely to immediately use their tokens, some are stored away etc.

4. Conclusion

We discussed how native currencies can add value and sketched a methodology for valuing crypto-tokens that utilized supply and demand equilibrium and the quantity theory of money.

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