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ABSTRACT

This paper explores how entrepreneurs can use initial coin offerings — whereby they issue crypto tokens and commit to accept only those tokens as payment for their products — to fund venture start-up costs. We show that the ICO mechanism allows entrepreneurs to generate buyer competition for the token, giving it value. We find that venture returns are independent of any committed growth in the supply of tokens over time, but that initial funds raised are maximized by setting that growth to zero to encourage saving by early participants. Nonetheless, since token value depends on a single period of demand, their ability to raise funds is more limited than traditional equity finance. A lack of commitment in monetary policy does, however, undermine saving, and therefore the cost of using tokens to fund start-up costs is inflexibility in future capital raises. Crypto tokens can also facilitate coordination among stakeholders within digital ecosystems when network effects are present.

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1. Introduction

Initial coin offerings (ICOs) have emerged as a novel mechanism for financing entrepreneurial ventures. Through an ICO, a venture offers a stock of specialized crypto tokens for sale with the promise that those tokens will operate as the medium of exchange when accessing the venture's products. The sale of tokens provides capital to fund initial development, although no commitment is made as to the price of future products (in tokens or otherwise).[2] Since 2017, blockchain startups have raised over $7B through initial coin offerings[3] compared to $1B through traditional venture capital flowing into the space (Catalini et al., 2017). Approximately one third of all ICO funding went to US-based teams, and more than 200 ICOs raised above $10M. Among recent offerings, Tezos raised $232M for developing a smart contracts and decentralized governance platform; Filecoin $205M from over 2,100 accredited investors to deploy a decentralized file storage network; Kin $98M to build a decentralized social network and communication platform; Blockstack $52M towards a decentralized browser, identity and application ecosystem; BAT $35M to develop a blockchain-based digital advertising ecosystem.

While the idea of issuing firm-specific tokens dates back to de Bono (1994), the recent spike in activity follows the invention of Bitcoin by Nakamoto (2008), and the development of cryptocurrencies with additional programming capability such as Ethereum. Using these platforms, a venture can fund its development with extremely low frictions through the issuance

[2] In this respect, token sales have a pre-sale aspect similar to crowdfunding, but differ in that there is no pre-sale price commitment to token holders (cf: Agrawal, Catalini and Goldfarb, 2013).

[3] To place this number into perspective, crowdfunding platform Kickstarter, over the course of 9 years, allocated a total of $3.5B to entrepreneurial and artistic projects. Equity crowdfunding platform AngelList, through its syndicated model, facilitated approximately $700M in online, early stage equity investments since 2013.

and auctioning off of dedicated crypto tokens. This is the result of blockchain technology lowering both the cost of verification of transaction attributes — which allows for self-custody of digital assets — and the cost of coordinating economic activity over the internet (Catalini and Gans, 2016).

This paper provides the first economic analysis of the ICO funding mechanism and how it relates to traditional equity financing. It addresses a simple issue: how can an entrepreneur, by issuing specialized tokens that have floating exchange rates against fiat-currencies, finance a new venture? Is this mechanism likely to fund the same type of ventures that are funded by venture capital firms and professional investors, or is it merely an opportunity to fund ideas that cannot be funded through traditional sources of capital? Conditional on the venture raising enough funds to develop its idea, which financing model maximizes returns?

These are open questions because, to date, no economic analysis has been conducted to explain how a token that can only be used to transact on a specific platform can have value in the absence of additional rights on the venture itself, its governance, or its future profits (as in traditional equity agreements). Here we abstract away from the notion that an entrepreneur might issue tokens and then deliberately fail to create a venture and examine a situation where the venture will be created — if viable — and where markets have developed to the point where pure fraud is not possible and teams without the ability to execute on their promises are unlikely to be funded (i.e. a market for curation of token offerings has emerged). Even in the absence of fraud and incompetence, how precisely tokens have value in the absence of additional rights on the venture is not obvious.

We identify the key commitments entrepreneurs need to be able to make to successfully fund their venture through this new mechanism, and discuss how the monetary policy of a token may influence fundraising and platform growth. We also examine key limitations of initial coin offerings that do not include the rights typically associated with equity ownership (i.e. that are not crypto securities), and if they can be used to assist ventures facing network effects in avoiding coordination problems (i.e., if they can help new entrants attract users and complements away from incumbents when existing players control a large share of pre-existing transactions).

The model delivers a number of new insights: the ICO mechanism allows entrepreneurs to generate buyer competition for the token, which ensures the token will have on-going value. Interestingly, conditional on successfully raising enough funds to cover development costs, the value of an ICO is independent of the anticipated growth of the venture. At the same time, the results unravel if the venture cannot credibly commit to the original money supply schedule, or if the commitment to using the token as the only medium of exchange is violated.

Furthermore, a perfectly viable venture, which could have successfully raised capital through traditional sources, may fail to raise enough funds to cover its costs through an ICO. This issue is particularly severe when the venture is long-lived, and is consistent with the rise of hybrid arrangements where ventures raise a traditional venture capital round before issuing tokens to the public or to accredited investors. While the returns to the platform (which often constitutes an open source software protocol and can be considered as "shared infrastructure" among all participants within an ecosystem) can be appropriated by all early stage investors through the direct appreciation of the token, the returns to the broader set of products the venture may create over time (e.g. new applications on top of the shared protocol) only accrue to equity holders. Because of the inherent uncertainty about which component will be more valuable in the long run — between the underlying protocol and the additional products a venture or third-parties may develop on top of it — venture capital firms have started writing hybrid contracts where they receive both tokens and equity in exchange for funding.

There has been a burgeoning literature studying cryptocurrencies and their use in entrepreneurial finance. There has been a wealth of empirical papers examining different aspects of ICOs (Catalini, Boslego, and Zhang, 2017; Benedetti and Kostovetsky, 2018; Howell, Niessner and Yermack, 2018; Momtaz, 2018) although these are yet to draw on theory. On the theoretical side, some papers examine the role of cryptocurrencies in the adoption of platforms (Cong, Li and Wang, 2018; Fisch, 2018; Li and Mann, 2018), while others have examined technical conditions regarding blockchains as a sustainable mean of preserving cryptocurrency commitments (Halaburda and Sarvary, 2016; Biais, Bisiere, Bouvard and Casamatta, 2017; Budish, 2018). While we discuss platform implications towards the end of the paper, our main focus is the more general idea of using tokens as venture-specific media of exchange. In addition, we abstract away from issues of blockchain stability and, instead, use blockchain to motivate key commitments — specifically to the supply of tokens — that are now feasible because of the technology. Finally, and most closely related to this paper, is research that examines the financial market characteristics of crypto tokens (Sockin and Xiong, 2018; Chod and Lyandres, 2018; Canidio, 2018). Those papers explore distinct issues including the role of information asymmetry between investors and the entrepreneur (Chod and Lyandres), or between platform users (Sockin and Xiong), and the ability for investors to appropriate tokens without developing a service (Canidio). Our model is, in a sense, more baseline in that it focuses on the role and determinants of cryptocurrencies in the absence of these factors. Thus, this theoretical research can be regarded as complementary to our own.

We proceed by building a simple model starting from the familiar situation of an entrepreneur who needs to raise equity financing from a venture capitalist because of financing constraints (Section 2). We use this template for equity financing as our baseline, and then benchmark it against initial coin offerings (Section 3). In Section 4, we study what happens when the venture faces a standard demand function, when there are ongoing costs, and when additional third-parties provide services using the token launched by the venture. Section 5 looks at imperfect commitment, and in particular at what happens when the venture cannot commit to a pre-determined monetary policy or to making the token the only medium of exchange. Section 6 explores ICOs in the presence of network effects. The last section concludes.

2. Model Set-Up

We model an entrepreneur who faces an upfront cost, C, of creating a venture. Once these costs are sunk, the venture can deploy its solution and start operating in the following period. There are three time periods, $t \in \{0,1,2\}$, and all agents in the model have a common discount factor, $\delta \in [0,1]$. Revenue can only be generated one period after the venture is launched. Thus, our focus is on how a liquidity constrained entrepreneur raises pre-revenue funds to finance the upfront development costs of their venture.

The quality, q, of the product created by the venture is distributed according to a cdf, $F(q)$, on the domain $[0, 1]$. There is a continuum of buyers on $[0, n_t]$, each placing the same value, q, on product quality. Here, n_t is a measure of demand at time t where we assume that $n_0 = 0$. With this set-up, there is a single parameter of demand, q, that is unknown. This is standard in many models in the entrepreneurial finance literature although here we additionally simplify matters by making all buyers ex post symmetric in their valuation of the product.[4]

We assume that initially no one knows true quality (including entrepreneurs and potential buyers. Once C is sunk (and the venture is created), all buyers and the entrepreneur learn the product quality, q.

No financing constraint

As a benchmark, suppose that the entrepreneur does not have a financing constraint (and has C in funds). When the venture is launched, q becomes common knowledge and so the entrepreneur sets $P = q$. Given this, the venture will be launched if:

$$\delta(n_1 + \delta n_2)E[q] \geq C .$$

Equity financing

Suppose now that there is a competitive venture capital market that can provide C to liquidity constrained entrepreneurs. How much equity (i.e., a share of profits, $1-\alpha$) will an entrepreneur need to cede in order to obtain C ? If the investor does not have credible knowledge of q prior to financing, the minimum equity they will accept and still finance the venture is:

$$1-\alpha^* = \frac{C}{\delta(n_1 + \delta n_2)E[q]}$$

Thus, the entrepreneur's expected return is:

[4] We use the term 'product' here because there is nothing in the model below that restricts the outcome to digital services per se even though all of the use cases we have seen to date are digital services. Of course, this definition of product is an economic one that encompasses digital services as a special case.

$$\alpha^{*}\delta(n_1+\delta n_2)E[q]=\delta(n_1+\delta n_2))E[q]-C\ .$$

As in the no financing constraint case, whether a venture proceeds or not depends upon whether the expected quality is greater than the venture costs.

3. Initial Coin Offerings

In an initial coin offering (or ICO), entrepreneurs specify an amount they aim to raise. That amount is usually a cap, and the entrepreneurs may retain a share of the tokens offered and be exposed to fluctuations in the value of their crypto token. The timeline is as follows:

1. ICO stage
   - The entrepreneur sets the quantity of tokens m_0, the minimum price each token will issue at, e (e.g. in exchange for dollars); the share of tokens the entrepreneur will retain, a, and whether the ICO is made contingent on $(1-a)m_0$ tokens being purchased ex ante. The entrepreneur also specifies the tokens available in the following periods 1 and 2 (m_1 and m_2).
   - The entrepreneur then auctions the tokens (in either a multi-unit English auction or second price auction). Other agents decide to purchase tokens or not.
   - If the total purchases exceed the minimum threshold, the entrepreneur proceeds with the venture, otherwise all contributions are returned, the venture does not launch and the game ends (this is similar to the provision point mechanism adopted on crowdfunding platforms).
2. Market stage
   - One period after the venture is created (through the sinking of cost C), product quality is revealed to all uninformed agents.
   - The entrepreneur launches the venture with tokens being the only accepted medium of exchange for its products.
   - Buyers trade tokens at a new market determined exchange rate.
   - Payoffs and profits are released.

Following Athey et.al. (2016), in such a context a dynamic price equilibrium requires the following:

(a) (Agent optimization) Each buyer chooses to purchase products on the platform in period t if $e_t p_t \leq q$. An agent chooses to purchase tokens at the end of a period if $e_t \geq \delta e_{t+1}$. The venture sets a price in each period t to maximize $e_t p_t D(e_t p_t)$ where $D(e_t p_t) = \# I_{e_t p_t \leq q}$ (that is, the number of units purchased). The choice of (m_1, m_2, a) maximizes the expected net present discounted value of venture profits.

(b) (Market clearing) The market for tokens clears at the maximum exchange rate such that the demand for tokens is less than supply.

(c) (Rational expectations) Agents' expectation of next period's exchange rate are correct.

Market stage

To examine this process, we work backwards and start by examining the final market stage. Suppose that m_t tokens are available at time t. The following proposition characterizes the (token-denominated) price, p_t, set by the entrepreneurs given their knowledge of q.

Proposition 1*. A dynamic price equilibrium exists where $p_t^* = m_t / n_t$ and all consumers with a positive value for the products purchase them during the market stage.*

The proof is as follows. If the product quality is revealed to be q, then the individual demand for tokens in dollars will be $p_t e_t$ so long as $p_t e_t \leq n_t q$. In equilibrium, the exchange rate, e_t, will be set by market clearing. The exchange rate depends on whether $n_t p_t$ (token demand) is less than, equal to or greater than m_t (token supply). If $p_t < m_t/n_t$, then the products can be purchased without using all of the token supply. In this case, e_t will tend towards 0 in order to clear the token market. This will give the venture no revenue in dollar terms. If $p_t > m_t/n_t$ instead, tokens will be scarce and total token demand $p_t e_t$ will be less than q as some customers are excluded. Finally, if $p_t = m_t/n_t$, then the (aggregate) dollar demand for tokens will be exactly $n_t q$. This is, therefore, the optimal price choice for the product and so the exchange rate will be determined by: $q/e_t = m_t/n_t$. This occurs where $e(m_t) = n_t q/m_t$. In other words, all token holdings are used by consumers to purchase the venture's products.

It is useful to reflect on what this means from a pricing strategy perspective. Without tokens, the venture would price based on expected willingness to pay. With tokens, it does not have control over the exchange rate and so cannot directly price in that manner. Instead, what it does is target the number of units it wants to sell which, in this model, is the same as the number of consumers in each period. It then sets a *divide-the-money price* which would divide the available supply of tokens up equally among expected consumers. As we have seen, consumers then bid for tokens if they they wish to purchase products and thus, the exchange rate reflects their willingness to pay. As the venture is receiving payment for those tokens, the exchange rate — so long as it is stable — will give them dollar payments based on willingness to pay. Importantly, the pricing strategy of dividing the available money supply does not require the venture to have direct knowledge or even expectations of consumer willingness to pay: the scarcity of tokens induced by the pricing choice causes buyer competition that reveals consumer value. Similarly, it is the ability to choose price in this manner that gives tokens value post-issue, even in the absence of additional rights as in equity financing (i.e. crypto tokens do not need to be crypto securities to have value and attract investment by early buyers).

Note that Proposition 1 characterizes an equilibrium in the market stage but it is far from unique. At the beginning of a period, the venture may not have any tokens. In that case, when it sets p_t, it will receive tokens back as payment. However, there is nothing to guarantee those tokens are valuable once received. In particular, in period 2, those tokens are, by definition, of no value. Thus, the venture would be indifferent between setting any price level and could set p_t so high there is no demand for its products or so low that the exchange rate adjusts accordingly. Consequently, there are many possible equilibria but we focus on this one because it maximizes the on-going value of the tokens. However, in Section 4 (below), we consider a situation in which the venture has ongoing costs and hence, an incentive to set p_t so high there is no demand for its products. Nonetheless, we demonstrate that the pricing outcome in Proposition 1 is the unique equilibrium in that case.

The timing of payments

We now turn to consider the payments made in periods 1 and 2 of the market stage. Discounting means that a buyer purchasing a token worth q in dollars tomorrow will only be willing to pay δq for that token today. Therefore, for a given q, the venture will be viable if $\delta(n_1 + \delta n_2)q \geq C$. To see how this works, recall that in the market stage q is known to everyone. At the beginning of any period, there are m_t tokens on issue and consumers need to purchase tokens in order to pay a price, p_t, set by the venture. By the same argument discussed before, p_t will be set to be equal to m_t and so the exchange rate that clears the market will be $e(m_t) = n_t q/m_t$. As a result of this, by the end of the period, at least m_t tokens will be held by the venture. At this point, the venture can divest itself of those tokens immediately. However, the willingness to pay for those tokens by others will be δq. Thus, the venture is indifferent between divesting itself of those tokens or selling them to buyers in the next period. Regardless, the venture will earn q per period for any period after the initial period it operates in.

The initial two periods — the ICO stage and the first period of the market stage — involve a different timing of payments to the venture. Working backwards, if buyers hold m_0 tokens at the beginning of the market stage, they will use those tokens to purchase the product at an exchange rate of n_1q/m_0. If buyers choose not to save any tokens between periods 1 and 2, at the end of that period the venture will hold the entire supply of tokens. However, it does not receive any influx of dollar payments during that period (i.e., period 1).

It is useful to note that if the venture holds tokens at the beginning of period 2, it always has an incentive to release them. To see this, suppose that the venture holds a share, $1-a$, of m_2 (the tokens available in period 2). If it does not release any tokens, then $e_2 = n_2q / am_2$. In this case, its period 2 profits are 0. By contrast, if the venture releases those tokens, then $e_2 = n_2q / m_2$ and its profits are $(1-a)e_2 = (1-a)(n_2q / m_2)$. The intuition is simple: the venture does not earn any revenue in a period except by selling tokens. In the final period (i.e., period 2) this means that even if selling token depreciates the exchange rate, the venture will always find it profitable to sell its holdings.

Incentives to save

The supply of tokens in any given period is determined by several factors. First, how many tokens are on issue? We have already noted that, in period 0, m_0 tokens are issued. Suppose that m_1 and m_2 tokens are intended to be 'on issue' in periods 1 and 2. A specific parameter of interest will therefore be the growth rate in the money supply between periods 1 and 2 which we refer to as $g_m = \frac{m_2 - m_1}{m_1}$. Second, how many tokens are being saved that period for use in subsequent periods? Third, how many tokens are being released from holdings by the venture (or by others)?

To build the intuition, suppose that $g_m = 0$ (the money supply does not grow or shrink and stays at a constant, *m*). Working backwards, let $g_n = \frac{n_2 - n_1}{n_1}$ be the growth in demand between periods 1 and 2. Since period 2 is the last period, the exchange rate will be:

$$e_2 = \frac{(1+g_n)n_1 q}{m},$$

as there is no incentive to save beyond that period. In period 1 token holders have a choice between selling their tokens to consumers demanding access to the platform in that period, or saving them to sell them to consumers in period 2. Let *s* denote the share of token supply in period 1 that is saved. Tokens will be saved so long as $\delta e_2 > e_1$. The exchange rate in period 2 is independent of the amount of tokens saved in period 1 while $e_1 = \frac{n_1 q}{(1-s)m_1}$. Thus, as *s* rises, e_1 rises. In equilibrium, therefore, *s* will rise until $\delta e_2 = e_1$. It is easy to show that:

$$s = \max\left\{\frac{\delta(1+g_n)-1}{\delta(1+g_n)}, 0\right\}.$$

That is, there is a positive level of saving if and only if $\delta(1+g_n) > 1$. Note that all of the tokens in the ICO are saved for at least one period. If $s > 0$, then $e_1 = \delta e_2$; while if $s = 0$, then $e_1 = \frac{n_1 q}{m_1} > \delta(1+g_n)\frac{n_1 q}{m_1} = \delta e_2$. This means that the exchange rate will be increasing over time, while the token-denominated price of the product will fall regardless.

What happens when the money supply changes between periods 1 and 2? In this case,

$$e_2 = \frac{(1+g_n)n_1 q}{(1+g_m)m_1}.$$

If the money supply expands, this reduces the return to saving between periods 1 and 2. In particular:

$$s = \max\left\{\frac{\delta(1+g_n)-(1+g_m)}{\delta(1+g_n)}, 0\right\}.$$

If $s > 0$, then $e_1 = \delta e_2$, which means that e_1 falls as g_m rises; while if $s = 0$, then e_1 is independent of g_m.

To summarize, the incentives for token holders to save is a function of the expected growth in demand for the platform and of the expected growth in the money supply. If $g_m < \delta(1+g_n)-1$, then $s > 0$, while if $g_m \geq \delta(1+g_n)-1$, $s = 0$. Thus, by setting g_m, the entrepreneur can determine whether saving takes place between periods 1 and 2 or not. One choice the entrepreneur has is to set $g_m = g_n$, in which case, $e_1 = e_2$ and $p_1 = p_2$. This is the equivalent in this economy to the Taylor Rule for monetary policy that keeps prices stable (Taylor, 1993). Note, however, that this involves $s = 0$ as $g_m > \delta(1+g_n)-1$.

What about incentives to save between period 0 and period 1? Note, first, that there is no demand for tokens in period 0 other than for saving purposes. Therefore, $e_0 = \delta E[e_1]$. This also means that expectations regarding e_1 will determine the value of the tokens that the entrepreneur issues in period 0. Is there any reason for the entrepreneur to set $m_1 > m_0$? Suppose the entrepreneur does this. Then their expected return is:

$$e_0 m_0 + \delta E[e_1](m_1 - m_0) = \delta E[e_1]m_1 = \begin{cases} \delta \frac{n_1 E[q]}{m_1} m_1 = \delta n_1 E[q] & \text{if} \quad s = 0 \\ \delta^2 \frac{n_2 E[q]}{m_2} m_1 = \delta^2 n_2 E[q] \frac{m_1}{m_2} & \quad\quad s > 0 \end{cases}$$

The entrepreneur's return is independent of m_0. Thus, we can assume that $m \equiv m_1 = m_0$ in what follows without loss in generality. Moreover, from this we can also see that it is only the intended g_m (between periods 1 and 2) that matters and not the level of m per se.

ICO Stage

At the ICO stage, the entrepreneur cannot launch the venture unless it expects to earn enough from the ICO to cover development costs C, i.e. unless $e_0 m \geq C$. The value of e_0 will depend upon whether the token is expected to be saved between periods 1 and 2. Specifically, $e_0 = \delta \frac{n_1}{m} E[q]$ (when $s = 0$) or $e_0 = \delta^2 \frac{n_2}{m_2} E[q]$ (when $s > 0$). Thus, the ICO will be viable (that is, will finance start-up costs), if:

$$\begin{matrix} \delta n_1 E[q] \geq C \\ \delta^2 n_1 \frac{1+g_n}{1+g_m} E[q] \geq C \end{matrix} \quad \text{for} \quad \begin{matrix} 1+g_m \geq \delta(1+g_n) \\ 1+g_m < \delta(1+g_n) \end{matrix}$$

It is straightforward to see that savings choices will be made in such a way that e_0 is maximized. The entrepreneur will, therefore, only proceed with the ICO if either of these conditions is satisfied as competition amongst token purchasers will ensure that $e_0 m = \max\{1, \delta \frac{1+g_n}{1+g_m}\} \delta n_1 E[q]$.

It is useful to note that a venture does not gain from retaining a share ($a > 0$) of tokens. We already noted that there is no return to the entrepreneur from saving tokens between periods 0 and 1. That means that the value of retaining a share of tokens arises in order to hold on to those tokens from period 0 to period 2. Recall that the entrepreneur will always want to sell any holdings in period 2. Therefore, if a is the share of initial tokens issued (m) retained by the entrepreneur, the exchange rate in period 2 will be $e_2 = \frac{n_2 E[q]}{m(1+g_m)}$, and so the return to retaining a share a would be $\delta^2 e_2 - \delta e_1$ which is only non-zero if $s = 0$. In that case, the return to retaining tokens equals to $\delta(\delta \frac{n_2 E[q]}{m(1+g_m)} - \frac{n_1 E[q]}{m(1-a)})$, which is negative for g_m high enough so that $s = 0$. What this means is that retaining a share of tokens does not perform any function than would otherwise be performed by setting $g_m > 0$, and selling new tokens into the market (e.g. through an auction) after the ICO stage and earning seigniorage. Thus, the committed growth in the supply of tokens is the main instrument that can impact the value of an ICO. If $s > 0$, then $e_0 = \delta^2 E[e_2]$, which means that e_0 falls as g_m rises. If $s = 0$, then e_0 is independent of g_m.

What g_m maximizes the returns of the entrepreneur? If $g_m < \delta(1+g_n)-1$, then $s > 0$ and so the total value of tokens issued in period 0 depends (negatively) on g_m. Importantly, this means that the value of the ICO is driven in part by anticipated growth in demand for the digital platform. By contrast, if $g_m \geq \delta(1+g_n)-1$, $s = 0$, then the total value of tokens issued in period 0 is independent of g_m. In addition, the value of the ICO is independent of anticipated demand growth. Interestingly, if $g_m < \delta(1+g_n)-1$, then the value of the ICO with anticipated saving is greater than the value without it, and that value is falling in g_m. Thus, the value of the ICO is maximized with $g_m = 0$.[5] This implies that the ICO will be viable so long as $\max\{1, \delta(1+g_n)\}\delta n_1 E[q] \geq C$.

However, we have to ask whether venture profits are maximized by keeping the money supply fixed over time. Ignoring, for the moment, whether the ICO value covers C or not, net of C, the expected profits of the venture when $s > 0$ are:

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[5] Actually being able to 'retire' tokens that are not saved would increase this further. We implicitly rule out this possibility here.

$$
\begin{aligned}
&e_0 m + \delta^2 E[e_2](1-s+g_m)m \\
&= \delta^2 \frac{(1+g_n)n_1 E[q]}{(1+g_m)m}\left(\frac{\left(1+\delta(1+g_n)\right)(1+g_m)}{\delta(1+g_n)}\right)m \\
&= \delta\left(1+\delta(1+g_n)\right)n_1 E[q]
\end{aligned}
$$

By contrast, if $g_m \geq \delta(1+g_n)-1$, s = 0, then the expected venture profit is:

$$
\delta\frac{n_1 E[q]}{m}m + \delta^2\frac{(1+g_n)n_1 E[q]}{(1+g_m)m}(1+g_m)m = \delta\left(1+\delta(1+g_n)\right)n_1 E[q]
$$

Thus, the outcomes with and without saving are equal and independent of g_m. By setting g_m =0, the venture can shift funds forward without changing the expected revenues from the platform. Of course, it may have other goals in mind such as price stability (which would be necessary for facilitating the use of a token as a medium of exchange). One way this can be achieved is by setting $g_m = g_n$ (thereby causing s = 0). In this situation, the exchange rate and token-denominated price, p, will be constant over time. The following proposition summarizes these results:

Proposition 2. *The amount raised in an ICO is maximized by setting* $g_m = 0$*, while, conditional on raising sufficient funds to cover C, the expected net present discounted value of venture profits is independent of* g_m.

Comparison with equity finance

We are now in a position to compare the returns to an ICO to traditional equity finance. Recall that the expected returns from an ICO are $\delta\left(1+\delta(1+g_n)\right)n_1 E[q] - C$ while the returns from equity finance are $\delta(1+\delta(1+g_n))n_1 E[q] - C$. Thus, they are equivalent conditional on each being viable. However, while equity finance is viable whenever the expected return to the venture is positive, this does not hold for an ICO.

To see this, recall that the maximum ICO funds will be:

$$e_0 m = \begin{cases} \delta^2(1+g_n)n_1 E[q] & \text{if} \quad 1<\delta(1+g_n) \\ \delta n_1 E[q] & \quad\;\; 1\geq \delta(1+g_n) \end{cases}$$

What this implies is that the ICO could involve a short-fall relative to C even if total venture gross profits would otherwise exceed C. Total venture revenues are $\delta\left(1+\delta(1+g_n)\right)n_1 E[q]$, which is the present value of period 1 plus period 2 revenues, whereas the ICO is based on the greater of the present values of period 1 and period 2 revenues. This arises because tokens that do not grant their holders additional dividend, voting, and control rights do not entitle holders to a stream of returns, but are instead ‘cashed in’ at a given point in time by investors. This issue is even more stark when the venture has customers across more than 2 periods in the market stage (e.g. when it plans to enter multiple industry verticals over time). For example, an infinitely lived venture (with no growth) will be viable if $\delta n > (1-\delta)C$, whereas an ICO in which the tokens do not constitute a crypto security will only raise at most $\delta n E[q]$.

This illustrates a significant limitation of ICOs compared to equity finance that is an issue when the venture is expected to be long-lived, and is consistent with the use of pre-ICO, equity-based rounds in this space where traditional VCs have funded startups before the venture and tokens go live. The development of tokens that have similar rights and features of traditional securities (crypto securities) may alleviate this problem, although it also introduces new issues around the allocation of returns between token holders and crypto equity holders which are beyond the scope of this paper.

4. Extensions

Standard demand function

The "divide the money" pricing rule is simple here because there is a known number of consumers in each period, n_t, each of whom have the same value for the product. A natural question to ask is what this rule looks like when the venture faces a smooth demand function that reflects consumers who have different willingnesses to pay for the product.

Let's denote that demand function by $n_t = D(e_t p_t)$. In this scenario, what is the optimal pricing choice for the venture at time t? If the available money supply is m_t, then the venture can target a particular n_t (call it n_t^*) by choosing $p_t^* = \frac{m_t}{n_t^*}$. At this price, for a given exchange rate, e_t, the total dollar demand for tokens will be $n_t^* e_t p_t^* = n_t^* D^{-1}(n_t^*)$, which must equal to the dollar token supply of $e_t m_t$, yielding an equilibrium exchange rate of $\hat{e}_t = \frac{n_t^* D^{-1}(n_t^*)}{m_t}$. Given this, what n_t^* will the venture target? The venture's dollar profits are $n_t^* D^{-1}(n_t^*)$ and, thus, if it were to maximize the value of the tokens on issue, it will determine quantity at its revenue maximizing point which, in this case, is equivalent to a point where the elasticity of demand is unity. Once again, as with Proposition 1, this is an equilibrium outcome of the dynamic pricing game, but is not necessarily the unique outcome.

Ongoing costs

While the "divide the money" pricing outcome is an equilibrium that implements a positive on-going value for the tokens, it rests on the indifference the venture has between maximizing profits (revenue) in each period and other goals it may choose including supplying no one or everyone. Those latter goals, however, will cause in equilibrium distortions to the value of the tokens that would harm the ability of the venture to raise funds in an ICO. The indifference condition, however, rests on there being no ongoing costs in supplying products to token holders.

Suppose that the marginal (dollar) cost of supply of a product to each consumer is $c > 0$. For the moment, we assume that realized q exceeds c. (If it does not, the venture will shut down even after sinking C). In this case, the venture at time t is no longer indifferent between supplying the product to n_t consumers versus another option. In particular, since the venture has issued tokens to others in return for dollars, it receives no additional benefit from supplying the product while it now incurs dollar costs of cn_t . Clearly, in this situation, it would prefer to supply no products. Anticipating this, the value of the token at the ICO stage (or any other stage) would be zero.

This is a potentially devastating outcome from a token value perspective. In this model, as it involves finite time, the usual remedies for such collapse that involve the use of relational contracts do not resolve this dilemma: it is as if there is a finite time game going on even if the demand for the venture's product extends indefinitely into the future.

That said, what if, at the beginning of any market stage, t, but prior to setting the token-denominated price of the product, p_t, the venture is required to hold a share, a, of all tokens on issue? It could achieve this by either acquiring or holding on to those tokens at the end of the previous period, t-1. However, after it has set its prices for that period, it would be free to sell those tokens into the market in order to facilitate transactions. The key condition is that they hold a share, a, when they commit to a token-denominated price. In this case, the expected dollar profit to the venture in that stage would be $ae_t p_t n_t - cn_t$. If $p_t = \frac{m_t}{n_t}$, then $e_t = \frac{n_t}{m_t} q$ and so expected dollar profits would be $aqn_t - cn_t$. In this case, so long as $a \geq \frac{c}{q}$, the venture would choose to supply the entire market using the "divide the money" price.

Interestingly, while by Proposition 2, conditional on being financed, the expected return to the venture is independent of g_m, the requirement to hold a share of tokens does not reduce expected returns. However, also by Proposition 2, the requirement may limit the funds that can be raised in an ICO, and so much so that the venture cannot raise enough to cover its development costs C. This raises the issue as to whether anything can be done to reduce the minimum level required to ensure that a venture facing ongoing operational costs continues to set a "divide the money" price and serve all consumers each period.

There is a potential solution and commitment that ventures can use to overcome this problem: requiring the tokens to be used as a medium of exchange for all transactions with the venture. Thus, rather than paying for costs in dollars, the venture could commit to only paying potential suppliers (of infrastructure, capital or labor) in tokens. The dollar marginal cost will remain c, but the venture will choose an amount w_t to pay for the supply of resources to produce an additional unit. Clearly, for this to occur, $e_t w_t \geq c$. In addition, the venture will have to, in each period, either purchase tokens themselves and/or retain a share of tokens, a, to be able to pay suppliers. Thus, the venture will require in total, cn_t, in terms of the dollar value of tokens.

The market for tokens at the beginning of a period in the market stage will be impacted upon depending on whether the venture trades in them or not. If $ae_t m_t \geq cn_t$, the venture will not need to purchase tokens and the exchange rate will be determined by $qn_t = e_t m_t - cn_t$ in a similar manner to the case where there are no ongoing costs. However, if $ae_t m_t < cn_t$, then the venture will also have to make some purchases in the market. In this case, the exchange rate will be determined by $qn_t + c_t n_t - ae_t m_t = (1-a)e_t m_t$. It is easy to see that these give equivalent outcomes where $e_t = \frac{n_t}{m_t}(q+c)$.

Given this, the venture will choose $n(\leq n_t)$ to maximize $ae_t m_t - cn = a(q+c)n - cn$. If $aq \leq (1-a)c$, it will choose n = 0. Otherwise it will choose $n = n_t$. Thus, the minimal level of a that can achieve this outcome is $a = \frac{c}{q+c}$. Under these conditions the maximum ICO funds will be:

$$E[(1-a)e_0 m \mid q \geq c] = \begin{cases} E[(1-\frac{c}{q+c})\delta^2(1+g_n)n_1(q+c) \mid q \geq c] & \text{if } 1 < \delta(1+g_n) \\ E[(1-\frac{c}{q+c})\delta n_1(q+c) \mid q \geq c] & \text{if } 1 \geq \delta(1+g_n) \end{cases}$$

which simplifies to: $E[(1-a)e_0 m \mid q \geq c] = \delta n_1 \max\{\delta(1+g_n),1\} E[q \mid q \geq c]$.

This demonstrates that a combination of requiring all transactions (including payments by the venture) to be conducted in tokens, and a minimum level of holdings by the venture at the beginning of a market period, can help ensure that the venture supplies the product to the optimal number of consumers. That said, this requirement limits the amount the venture can earn during the ICO. Thus, one might conclude that ICOs become less preferable as c increases.

While it is true, however, that a higher c makes a venture less desirable under an ICO, it also makes a venture less desirable per se. We are therefore interested in whether an increase in c makes financing via an ICO less desirable relative to financing via equity finance. To see this, note that q is not known at the time of the ICO even if it is known at the beginning of any given market stage. Thus, the condition for whether the venture can proceed is:

$$\delta \max\{\delta(1+g_n),1\} n_1 E[q \mid q \geq c] \geq C$$

By contrast, when there are on-going costs, the feasibility condition under equity finance is:

$$\delta(1+\delta(1+g_n))n_1 \left(E[q \mid q \geq c]-c\right) \geq C$$

Comparing these, we have an ICO being preferred to equity finance if:

$$(1+\delta(1+g_n))c \geq \left(1+\delta(1+g_n)-\max\{\delta(1+g_n),1\}\right)E[q \mid q \geq c]$$

In a general form, it is difficult to determine whether this can hold, since an increase in c raises both sides of the inequality. But suppose that q is uniformly distributed on [0,1] with $c < 1$. In this case, $E[q \mid q \geq c] = \frac{1}{2}(1+c)$, and the above inequality becomes:

$$\frac{\max\{\delta(1+g_n),1\}}{1+\delta(1+g_n)} \geq \frac{1-c}{1+c}$$

It is easy to see that this will hold only for c sufficiently high.

In effect, when there are ongoing costs, the ICO has an advantage in that it is raising funds based on overall transactions — that is, on both the supply and the demand side — rather than operating margins as would be the case of equity finance. Thus, as ongoing costs rise, the advantage over equity finance that is based on the aggregate level of profits becomes lower.

Third-party products and products

Thus far, we have explored a situation where the tokens are the exclusive medium of exchange, and consumers can only spend tokens to purchase products from the venture. This represents a simplification of how the technology in used in practice, as tokens are issued to crowdfund and bootstrap economic activity around digital ecosystems that are broader than the venture itself. While the venture, especially in the early stages, often represents the key economic actor within such ecosystem, its objective is to use incentives and market design to facilitate transactions that extend beyond the venture, and create the right conditions for other participants to join its 'economy'. The venture could design incentives in a way to crowdsource talent and labor (e.g. Numerai), or other key resources the ecosystem needs to scale such as computation (e.g. Bitcoin, Ethereum), storage (Filecoin, Sia), electricity (Grid+), digital content and data (e.g. BAT), etc. For example, in the case of a token designed to create a competitive marketplace for data storage and data services, hard drive manufacturers and data centres could join the digital platform developed by the venture and sell their services directly to consumers in exchange for tokens. Third-parties can also use the shared infrastructure deployed by the venture to develop applications on top of it that take advantage of the underlying token to settle transactions and allocate resources.

Whereas until now we assumed that all these different types of third-parties are vertically integrated with the venture, in this section, we explicitly explore the case where they are actually separate entities. To consider this, we return to the situation where there are no on-going costs (i.e., $c = 0$ and the platform is purely digital) but assume that, in addition to the venture's services, other suppliers can accept tokens as payment in each period involving a market stage.

To keep things simple, we assume there is a single third-party supplier who charges a token-denominated price of w_t. We assume that this supplier is the exclusive purchaser of products from the venture and pays a token denominated price of p_t to the venture to keep the platform running (e.g. so that the venture can keep updating and maintaining the codebase). Last, to keep the model as close as possible to our baseline, we assume that the third-party supplier's customers place a value of q on their product which is initially unknown and that there are n_t such customers in each period.

It is easy to see that, in each market stage, the total demand for tokens will be $w_t n_t$ as the third-party supplier's customers and the supplier itself require tokens to transact on the platform, but the payment on the platform, p_t, is purely internal so does not (on net) impact token demand. Notice, however, that if the venture set its price before the third-party supplier sets its price, the venture will set a divide the money price leaving the third-party to do the same. In this case, the dollar demand for tokens will be qn_t, and the exchange rate will be the same as the baseline model. In other words, this structure does not change the choices the venture faces or the condition for successful financing via an ICO.

That said, if the third-party supplier has its own costs, c, it will need to earn tokens of sufficient value to cover these costs. This will not happen if the venture sets a divide the money price of $p_t = m_t / n_t$. To encourage the third-party supplier, the venture could commit to receiving a share, b, of the token payments made to the third-party, w_t. In this case, the third-party will set a divide the money price, $w_t = m_t / n_t$, and will find it worthwhile to enter so long as $(1-b)q \geq c$.

Given this, the venture's expected profits are: $\delta \max\{\delta(1+g_n),1\} n_1 E[q \mid (1-b)q \geq c] - C$. Note that these are decreasing in b and so will be maximized by setting b = 0. This is because when the venture issues tokens, as mentioned before, the initial demand for tokens is based on a single period of token demand. So long as the third-party supplier enters, the venture will be able to appropriate the full value of a seller for the period with the maximum discounted value of tokens. Thus, its incentive is to ensure the third-party supplier enters for the widest feasible range of q. This is achieved by foregoing future payments on the platform.

5. Imperfect commitment

The analysis thus far has assumed that the venture can perfectly commit to (a) only accepting tokens for access to the digital platform; and (b) that the supply of tokens is stated upfront for each period and does not change under any circumstance. Whereas both commitments are fundamentally promises by the founding team, they are typically reinforced by making the underlying codebase available as open-source software and by hardcoding the money supply schedule within the software protocol. We now explore the implications of relaxing the assumption that such commitments are credible.

Money supply commitment

It is a cornerstone of monetary economics that for money to perform its function it is important that its supply be tightly controlled. The same is true for crypto tokens, but there is some nuance here.

To begin, suppose that while the venture can commit to m_0 and m_1, it cannot commit to m_2. Suppose also that between periods 1 and 2 some saving is taking place (ie., $s > 0$). In this case, the period 2 venture profits would be: $e_2 p_2 n_2 - e_2 s m_1$. Given that the venture still commits to only accepting tokens for access to the platform, it uses a divide-the-money price of $p_2 = \left(m_2 + s m_1\right)/ n_2$, while $e_2 = n_2 q / \left(m_2 + s m_1\right)$. Thus, its profits are $q n_2 - \frac{s m_1}{m_2 + s m_1} n_2 q$, which is increasing in m_2. If $s > 0$ and the venture is uncommitted to m_2, then it has an incentive to set m_2 as high as possible. Put simply, it has an incentive to inflate prices precisely because it does not appropriate any return from past saving. Given this, when the commitment to m_2 cannot be enforced, no saving will take place.

It is useful to note that, if the venture retained its own share of m_1, this does not alter these incentives to expand the money supply. This is because the venture has an incentive to dispose of such retained holdings in period 2, and these have the same profit impact as any expansion in m_2. Thus, regardless, the venture has an incentive to set m_2 as high as possible if $s > 0$.[6]

Being unable to commit to m_2 has potentially an impact on the ICO. Recall that committing early to $m_1 = m_2$, while not changing the expected return to the venture, shifts forward earnings so that the venture can fund C upfront. In other words, a lack of commitment may mean some otherwise viable ventures may not be funded through an ICO. Interestingly, when this is not a constraint, a lack of commitment on the money supply is not a problem for the venture. While that lack of commitment means that saving will be discouraged, there is an upside when there is no saving. If the venture holds all of the tokens, it is free to change how it operates after the

[6] In practice, the use of a extremely long vesting schedule could delay this issue. However, this depends on the commitment to the money supply over that time period; something that will be useful to explore in future work.

period whereby investors have purchased tokens to fund *C*, and have recouped it by selling their token to would be users of the digital platform. In other words, when there is no function performed by saving tokens, there is no value to commitment and a lack of commitment is not an obstacle for the venture going forward.

A venture may, indeed, want to plan for such a break if it anticipates a need to raise funds to, say, finance activities that may grow the venture further. It may also find it advantageous if it wants an exit through an IPO or acquisition that is not encumbered by previous commitments. In summary, the conclusion here is that commitment is a cost the venture must incur in order to shift funds forward to cover *C*. The less such revenue shifting is required, the less commitment is needed. Whereas many have described ICOs as a potential substitute to traditional sources of funding such as angel and venture capital, this highlights their complementary nature to them.

Medium of exchange commitment

The other commitment is that the token will constitute the only way to access the digital platform developed by the venture. Suppose that this commitment was not maintained and the venture, in the market stage, sold products directly to consumers accepting dollars. For any buyer, the effective dollar price would be the same regardless of whether they purchased tokens or not to facilitate that transaction. As the venture sets its token-denominated price at the beginning of a period in the market stage, it has no incentive to set a price other than the divide-the-money price. With this price, it appropriates all consumer value which is the most it could get by setting a dollar-denominated price instead.

That said, these pricing incentives may change if, when it sets its price, tokens are held by others outside the venture. By setting a price above the divide-the-money price, no consumers would purchase tokens and the value of tokens would depreciate (or completely collapse). In particular, this may arise if there is saving between periods, and between the ICO and market stage. In other words, like the commitment not to change the money supply, the medium of exchange commitment is critical whenever tokens are held by others too. Imperfect commitment that allows the venture to later accept other means of payment for the technology, would give the venture incentives to set the price so as to have payments not denominated in tokens (e.g. dollar payments) go directly to the founding team. In this way, we can see the importance of this particular commitment for the viability of ICOs.[7]

6 . Network Effects

One of the purported benefits of ICOs is that they can assist ventures facing network effects in avoiding coordination problems. Such problems arise when unfavorable expectations about a network result in ventures having to use low pricing in order to generate adoption. By comparison, a venture facing favorable expectations can price at a high level and still generate adoption. Clearly, the more favorable the expectations, the greater the profits for the venture. We therefore ask whether it is possible to use an ICO and improve outcomes in the face of what would otherwise be unfavorable expectations.

To explore this, we amend the underlying demand so that the value to a consumer from the use of the venture's platform is $q(\alpha+\beta n_t)$ with $\alpha, \beta > 0$; that is, there is a one-sided network effect whereby the value of the platform increases as more users join. In this situation, the price

[7] The venture, Quantstamp, recently became embroiled in controversy when it did not adhere to a medium of exchange commitment for its platform for smart contracts and was accused of accepting other cryptocurrencies and US dollars for its services (Milano and Odayar, 2018).

that the venture can charge for access to the platform in a period depends critically on consumers' expectations regarding how many other users will join it. Using the terminology of Hagiu (2006), if expectations are favorable, then consumers expect others to join (i.e., $E[n_1]=n_1$), and the venture can charge a price of $p_1 = q(\alpha+\beta n_1)$ in the first period. If expectations are unfavorable instead (i.e., $E[n_1]=0$), then the venture can only charge a price of $p_1 = q\alpha$. Interestingly, at that price, all consumers join and receive a surplus of $q\beta n_1$ each. Note that there is nothing that carries over to period 2, regardless of who uses the product in period 1, so the same coordination problem for the venture exists in this context as well.

What if expectations are unfavorable with $E[n_1]=0$? Are such expectations sustainable if the venture uses an ICO? The short answer is no. We are aided here by the fact that it is common knowledge that consumers know the true value of the product *q*. That means that if there are bids for the tokens initially above the reserve, it is because *q* is sufficiently high. In that case, those bids will come from all consumers in period 1. Thus, the total bid volume, $e_0 m_1$, would be based on $\delta E[n] q(\alpha+\beta E[n])$ which implies that the exchange rate is a perfect signal of $E[n]$. The only equilibrium outcome in the ICO stage, therefore, is where $e_0 = \delta \frac{n_1}{m_1} q(\alpha+\beta n_1)$.

Note that unfavorable expectations is not an equilibrium outcome as it is based on expectations that are not fulfilled in equilibrium. Because all participants can see trading in tokens, this allows coordination to emerge.

The same pattern can hold in period 2 where the period begins with the venture holding all of the tokens and setting the price. The venture sets a divide-the-money price equal to m_2 / n_2

based on the assumption — fulfilled in any equilibrium — that if there are purchases they are from all consumers. At this price, consumers bid for tokens with the unique equilibrium outcome being $e_2 = \frac{n_2}{m_2} q(\alpha + \beta n_2)$. Note that if, for some reason, the venture assumed that it would have fewer than n_2 consumers — say, n — then it would set $p_2 = m_2 / n$. At this price, the exchange rate would adjust to $e_2 = \frac{n}{m_2} q(\alpha + \beta n)$. Thus, there would be rationing of customers. However, in this model, the only rational expectations consistent with the assumption of consumer symmetry are 0 and n_2, and the venture is indifferent between pricing based on these two outcomes since it expects 0 in either case. Therefore it can set a price based on full adoption. To relate this to the literature on network or platform pricing, note that the ICO makes the full price $e_t p_t$ an *insulating* tariff (Weyl, 2010). This is a tariff that makes it a dominant strategy for each consumer to adopt the product. That is, $e_t p_t \leq q(\alpha + \beta n_t)$.

7. Conclusion

The paper shows that entrepreneurs have an incentive to use subsequent product pricing choices to ensure that crypto tokens issued to fund start-up costs retain their value even when they do not confer the typical rights associated with equity (i.e. they are not crypto securities). Countering this are potential commitment issues that arise when agents other than the entrepreneur hold tokens for any period of time in the hope that the tokens will appreciate in value. While entrepreneurs will still price to retain token value, they may be tempted to issue more tokens post-ICO, expropriating early token holders. Thus, discretionary pricing is an important instrument in this context (as it allows for price discovery), whereas discretionary monetary policy is a major concern. Such constraints might bind if the entrepreneur needs to take advantage of the expectations of future demand to increase the value raised through an ICO and cover the development costs of a new digital platform.

References

Agrawal, A., C. Catalini, and A. Goldfarb (2013), "Some simple economics of crowdfunding," *Innovation Policy and the Economy*, 14 (1), 63-97.

Athey, S., I. Parashkevov, V. Sarukkai, and J. Xia (2016), "Bitcoin pricing, adoption, and usage: Theory and evidence," *mimeo*., Stanford.

Benedetti, H. And L. Kostovetsky (2018), "Digital Tulips? Returns to Investors in Initial Coin Offerings," *mimeo*., Boston College.

Biais, B., C. Bisiere, M. Bouvard and C. Casamatta (2017), "The blockchain folk theorem," *Working Paper* No.17-817, Toulouse School of Economics.

Budish, E. (2018), "The Limits of Bitcoin and the Blockchain," *mimeo*., Chicago.

Canidio, A. (2018), "Financial incentives for open source development: the case of Blockchain," *mimeo*., Insead.

Catalini, C. and J.S. Gans (2016), "Some simple economics of the blockchain," *mimeo*, MIT https://papers.ssrn.com/sol3/papers.cfm?abstract id=2874598.

Catalini, C., J. Boslego, K. Zhang (2017), "Technological Opportunity, Bubbles and Innovation: The Dynamics of Initial Coin Offerings", *mimeo*, MIT.

Chiu, J. and T.V. Koeppl (2017), "The Economics of Cryptocurrencies - Bitcoin and Beyond," *mimeo*., Queens University.

Chod, J. and E. Lyandres (2018), "A Theory of ICOs: Diversification, Agency and Information Asymmetry," mimeo., Boston College.

Cong, L.W., Y. Li and N. Wang (2018), "Tokenonomics: Dynamic Adoption and Valuation," *mimeo*., Chicago.

de Bono, E. (1994), "The IBM Dollar," Centre for the Study of Financial Innovation, London.

Fisch, C. (2018), "Initial coin offerings (ICOs) to finance new ventures: An exploratory study," *mimeo*., Trier.

Hagiu, A. (2006), "Pricing and Commitment by Two-Sided Platforms," *Rand Journal of Economics*, 37 (3), pp.720-737.

Halaburda, H. And M. Sarvary (2016), *Beyond Bitcoin: The Economics of Digital Currencies*, Palgrave MacMillan.

Howell, S.T., M. Niessner and D. Yermack (2018), "Initial Coin Offerings: Financing Growth with Cryptocurrency Token Sales," *mimeo*., NYU.

Li, J. and W. Mann (2018), "Initial Coin Offering and Platform Building," *mimeo*., UCLA.

Milano, A. and T. Odayar (2018), "Quantstamp under Fire: Buyers say faith shaken in $65 million token," Coindesk (14 June); https://www.coindesk.com/quantstamp-fire-buyers-say-faith-shaken-65-million-token/

Momtaz, P.P. (2018), "Initial Coin Offerings," *Working Paper* No.31, Hamburg Financial Research Center.

Nakamoto, S. (2008), "Bitcoin: A peer-to-peer electronic cash system," *mimeo*, unknown.

Sockin, M. And W. Xiong (2018), "A Model of Cryptocurrencies," *mimeo*., Princeton.

Taylor, J.B. (1993), "Discretion versus policy rules in practice," *Carnegie-Rochester Conference Series on Public Policy,* 39, pp. 195-214.

Weyl, E.G. (2010), "A price theory of multi-sided platforms," *American Economic Review*, 100 (4), pp.1642-72.