Tokenomics: when tokens beat equity[*]

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Abstract

In an initial coin offering, investors fund a venture in exchange for tokens that grant rights to future economic output. To many financial industry insiders, tokens have no intrinsic merit and exist only as a way to evade regulations. We demonstrate that generic revenue-based token contracts are indeed economically inferior to equity and lead to over- or under-production. However, an optimally designed token contract, which is a combination of an output presale and an incremental revenue sharing agreement, yields the same payoffs as equity. Moreover, with entrepreneurial moral hazard, tokens can finance a strictly larger set of ventures than equity.

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The last two years have witnessed an extraordinary development in the financing of start-up firms. In 2018, over 900 early-stage entities have raised an estimated 21.7 billion U.S. dollars by issuing blockchain-based tokens or coins, while bypassing most of the traditional financial industry.[1] To understand just how extraordinary this boom in the blockchain-based capital market is, consider the Canadian TSX Venture (TSXV), an established, very successful market for early stage firms. The 1,400 firms that have listed on this public market over the past 20 years have a total market capitalization of 41 billion US dollars; in 2018, the TSXV saw only 8 IPOs with a total raised of around 0.04 billion US dollars.

Despite the remarkable amount of funding raised, most financial industry insiders are deeply skeptical about tokens and coins as a financing tool. In contrast to traditional debt or equity financing, there is no established framework for blockchain-based tokens, their legal status is uncertain, and their economics is not well-understood. In this paper, we provide a simple theoretical model of token issuance to improve the profession's understanding of the economic functioning and merit of tokens.

In an initial coin offering (ICO), investors transfer funds, typically in the form of cryptocurrencies, to the issuer in exchange for blockchain-based tokens or coins. These tokens are formally pieces of computer code, or "smart contracts," that control the transfer of funds or assets between parties, and they are stored on a decentralized ledger, either on a blockchain specifically created for the ICO or on a pre-existing blockchain such as Ethereum.[2] The tokens' economic functions depend on the specific arrangements encoded by the smart contracts. Tokens may, for instance, represent traditional assets

[1] See https://www.coinschedule.com/stats.html.

[2] The Ethereum blockchain is a network that has been developed by volunteers and enthusiasts, mostly in Canada, without the direct involvement of any major corporation, tech company, or financial institution. In fact, the Ethereum Foundation could not run its 2014 crowdfunding campaign in Canada because no financial institution would give it a bank account.

if the corresponding contract is a debt or equity claim on the issuer. More commonly, however, tokens provide their holders with access to an application or service, by means of a blockchain-based infrastructure, without a transfer of ownership rights or claims to physical assets. These "utility" tokens are a major innovation in corporate financing and the focus of this paper.

Much of the public debate has focussed on legal uncertainty, disclosure requirements, and regulatory challenges. Blockchain technology allows the issuers to access broad pools of investors directly. By circumventing the traditional system of financial intermediaries, the founders are able to avoid (some of) the prohibitively high costs of capital raising in equity markets.[3] However, in side-stepping the established legal frameworks while marketing and selling tokens directly to the general public, the issuers are possibly violating securities laws.[4] The legal structure of the issuers themselves presents challenges, too, as many token-issuers are not-for-profit foundations and not corporations.

What is missing from the public debate is a rigorous discussion on the *economic* merit of the concept of a token merits of tokens and on the role that token-issuances can play in the financing of economic activity. The key question is whether the *economic* functions of tokens can enable investments that are otherwise not possible, or whether ICOs are indeed only advantageous because of regulatory and transaction cost arbitrage.

In this paper, we show that a well-designed token contract may lower the agency

[3]For public markets, a 2017 industry report estimates an average cost of $7.3M for firms that raise $25-100M; see https://www.pwc.com/us/en/deals/publications/assets/cost-of-an-ipo.pdf. The National Crowdfunding & FinTech Association of Canada provides cost estimates for private markets: https://ncfacanada.org/how-much-does-an-offering-memorandum-cost/.

[4]Several entities declared that their tokens are not securities because they would not assign ownership rights, and yet they described tokens as an investment opportunity in which investors could benefit from price appreciations. A prominent example is the sale of DAO (Decentralized Autonomous Organization) tokens, which the S.E.C. eventually declared to be securities. Having stood at the sidelines for a while, some regulators are now asserting their jurisdiction and in early November 2018, the S.E.C. charged several token issuers with security law violations.

costs that stem from conflicts of interest between the issuer and the investors. As a consequence, tokens can be used to successfully finance projects that would not receive equity-based funding, due to the costs of moral hazard, a common economic problem that plagues many early-stage firms.

Our work builds on Catalini and Gans (2018) and Chod and Lyandres (2018) who both argue that a typical token sale constitutes a presale of future revenue. Catalini and Gans (2018) provide the first framework that shows how tokens can be used to issue funds, and how token issuers' "monetary policy" —the issuance of future tokens— affect investors' willingness to provide funds. Chod and Lyandres (2018) model a token sale as a presale of a fraction of future revenue, and they show that this method of ICO financing leads to underinvestment relative to the venture capitalist financing.

Similarly to Catalini and Gans (2018) and Chod and Lyandres (2018), we model token-issuance as an alternative to equity financing that is available to a profit-maximizing entrepreneur. We do not consider the possible role of cryptocurrencies in platform adoption (see, e.g., Bakos and Halaburda (2018), Cong, Li, and Wang (2018), Fisch (2018), or Li and Mann (2018)).

In our model, a monopolist entrepreneur has an idea for a venture that would offer a particular good or service, and she requires set-up funds to build the platform that would provide this good or service. The demand for this good is uncertain, and it will only be realized after the set-up cost has been incurred and the platform is operational. In our baseline model, the demand distribution is exogenous; specifically, we assume a linear inverse demand with an uncertain intercept. In the second part of the paper, we generalize the model by allowing the entrepreneur to increase the expected demand (formally, the intercept of the inverse demand function) by, e.g., more aggressive promotional activities, better platform support, or more attentive monitoring of her employees. We assume that these promotional activities do not incur any monetary cost, but they decrease the payoff of the venture to the entrepreneur.

The entrepreneur may raise funds from investors, in exchange for equity, or in exchange for tokens that entitle the token-holders to a pre-specified share of the future output.[5] Differently to crowdfunding (see, e.g., Li (2016) and Cimon (2016)), the presale of the future output in a token offering allows for participation of investors who do not intend to use the entrepreneur's product or service, as they may resell the tokens in a secondary market. Investors do not have a preference for a financing method, and they will finance the venture as long as they break-even in expectation.

At time zero, the entrepreneur decides on the choice of financing, and at time one, once the initial investment has been made, she learns the demand function and chooses the profit maximizing quantity. In our baseline model, equity financing results in the profit-maximizing production choice by the monopolist, and all profitable projects can be financed by equity.

With token financing, the issuer has a choice of how to structure the offering, and first examine how this choice affects the venture's profitability. First, the entrepreneur can issue tokens in exchange for a *fraction* α of the future revenue. Mechanically, the entrepreneur will issue T tokens at time zero, pre-production, sell $t = \alpha T$ of these to the investors, and commit not to issue tokens in the future. Investors will then receive exactly the fraction α of the revenue, and each unit of goods or services will require T/q tokens when the total q units of output are produced. This method of financing, which we refer to as *revenue sharing*, leads to "under-production", relative to the profit-maximizing quantity, similarly to under-investment in Chod and Lyandres (2018). In contrast to

[5]As is common with early stage firms, we assume that the issuer cannot access credit markets.

equity financing where the entrepreneur shares *profits*, with *revenue*-sharing the entrepreneur bears the entire marginal cost and her production incentives are distorted.

An alternative way of compensating the token-holders is to pre-sell a certain amount of output, as is common with crowdfunding, instead of pre-selling a fixed share of the output. Mechanically, the entrepreneur will issue t tokens at time zero, pre-production, sell these to investors and pre-commit to a fixed token-to-output exchange rate. In this case, the entrepreneur does not commit ex ante to the total number of tokens to be issued, and will issue $q - t$ tokens to herself at time one, after the production decision for q units has been made. This method of financing, which we refer to as an *output presale*, generically leads to a very different type of agency conflict. When choosing the optimal output quantity, the entrepreneur fails to internalize the price impact that the production of an extra unit of output has on the token-holders. This externality leads to "over-production", relative to the production quantity that maximizes the venture's aggregate profits.

Our discussion above illustrates that the method of an ICO financing is critical to the success of the financing round. The two common revenue-based ICO choices both result in a production quantity that does not maximize the project's expected net present value. Consequently, there will be profitable projects that cannot be financed by either of these two methods, even in the absence of other agency costs and frictions.

One method leads to over-production, the other to under-production. We next show that an ICO contract that combines the output presale with revenue sharing can improve the entrepreneur's production incentives. A presale of a fixed amount of the future product to the token-holders generically imposes an externality on the latter: when the entrepreneur makes her production decision, she fails to internalize the price impact on the token-holders.[6] A traditional solution to correct for an externality is a tax. In this case, the optimal tax is levied on the entrepreneur's revenue through an appropriate token monetary policy: in addition to selling a set of initial tokens (which represent a claim to the units of output) to the investors, the issuer also commits to offer investors a share in the revenues from the tokens that are issued *after* the production decision.

The optimal dynamic token contract that combines the output presale with revenue sharing uniquely exists in our model, and a token issuance can be structured to ensure that the entrepreneur's choice of the production quantity maximizes the venture's total profits. Consequently, in our baseline model, all projects that can be financed by equity can also be financed by an ICO offering, and vice versa.[7]

In the second part of the paper we examine whether the choice of financing impacts the issuer's effort in making the venture a success. We model the impact of effort as a higher, on average, expected demand by customers, and we assume, as is common in the literature, that contracts are incomplete in that effort cannot be guaranteed or contracted upon. Our view is that this scenario is particularly applicable to the newly emerging "decentralized" economy that many token issuers promise to develop because traditional venture capitalist firms and angel investors may have a lesser understanding of this environment, and their advice and oversight may be less valuable.[8] We show that the capital structure equivalence breaks down in the presence of moral hazard, and that

[6]This externality does not feature in Chod and Lyandres (2018), as they assume a random output price that is not impacted by the entrepreneur's decision.

[7]The over- and under-investment cases both appear to trigger a violation of Modigliani and Miller's capital structure irrelevance. Likewise, the equivalence under the optimal contract looks like the classic Modigliani-Miller (MM) irrelevance result. MM does not apply, however, when the financing decision affects the production decision.

[8]Many of the projects in the blockchain universe involve developers who work largely independently in various locations around the world, making monitoring them a challenge. One can also imagine that an existing firm seeks financing for a particular new project, and that, once funds have been disbursed, financiers cannot monitor whether the firm actually spends the funds on the promised project.

tokens, not equity, offer the stronger incentives for the entrepreneur to exert effort.

The key insight is that the optimal token issuance has a flavor of debt-financing in the sense that the issuer only earns positive profits if the demand is sufficiently high, and she retains a higher fraction of the revenues when the produced quantity exceeds the pre-sold units. We find, in the spirit of the seminal Jensen and Meckling (1976), that the optimal token contract always makes the issuer choose at least the same effort level as the equity financing contract. Moreover, when moral hazard is particularly severe, the issuer only exerts effort under the token contract. Consequently, all profitable projects that can be financed by equity can also be financed with tokens, but some profitable ventures that can only be financed with tokens cannot be funded by equity.

In summary, tokens can deliver the same profits as traditional equity, and, in the context of our model, the optimal token contract is superior: it enables undertaking of profitable projects that cannot get equity financing from venture capitalists or angel investors. Policy makers and industry participants should therefore seek to develop rules and mechanism that allow issuers and investors —who clearly show interest in this new asset class— to come together and interact in a safe environment. Imposing IPO-level hurdles for token issuances, which are unsurmountable for early stage firms, may damage otherwise economically viable entities and harm economic growth.

I. Related Literature

Alongside the boom in token offerings, there has been a boom in the academic literature on token offerings. In November 2018, SSRN, which covers work from law and social sciences,[9] listed 87 papers, most which were written in the summer of 2018. A large

[9]Much of the discussion among users, investors, and often technologists, however, occurs on Reddit, Quora, and Medium.

fraction of this recent literature studies the legal and regulatory challenges presented by ICOs; see, among others, Chohan (2017), Kaal (2018), Barsan (2017), Dell'Erba (2018), Zetzsche, Buckley, Arner, and Föhr (2018), or, Blemus (2017).

A second strand of the literature examines the empirical performance of ICOs. Much of this literature focusses on the importance and relevance of the information that is revealed prior to the ICO, in particular in the ICO's so-called "whitepaper" which describes the technology and business objectives of the entity that the token offering finances. The common consensus is that better information in whitepapers leads to higher success probabilities and more funding; see Feng, Li, Lu, Wong, and Zhang (2018), de Jong, Roosenboom, and van der Kolk (2018), Adhami, Giudici, and Martinazzi (2018), Momtaz (2018a), Amsden and Schweizer (2018), Howell, Niessner, and Yermack (2018), Fisch (2018), Bourveau, De George, Ellahie, and Macciocchi (2018), Lee, Li, and Shin (2018), or Masiak, Block, Masiak, Neuenkirch, and Pielen (2018). Momtaz (2018b) additionally studies the relation of information disclosure for the long-run performance of ICOs.

A third strand of literature addresses whether the issuance of a token or platform-specific cryptocurrency can spur platform adoption. This case is not entirely clear. Sockin and Xiong (2018) model a cryptocurrency as a platform "membership token" in the sense that only this token is accepted for transactions, and as a miner compensation fee. In their model, the platform either fails or in which there are multiple equilibria. Li and Mann (2018) and Bakos and Halaburda (2018) both highlight that tokens can overcome possible coordination failures during platform operation, that they can establish strong network effects, and that they support equilibria that favor the particular platform. Cong, Li, and Wang (2018) develop an asset-pricing model of tokens and they show that, by facilitating transactions and by allowing community members to benefit from future growth, tokens can help coordinate and accelerate adoption, and improve economic welfare.

A key feature of most tokens is that they are tradable immediately after they have been issued. A fourth strand of the literature studies the token market structure and asset pricing implications. Several authors analyze coins and tokens as investment products; for instance, Li and Yi (2018) examine whether ICO returns adhere to an asset pricing factor structure; Benedetti and Kostovetsky (2018) describe the initial trading returns for token investors. Malinova and Park (2016) study the impact of the intrinsic transparency of blockchain transactions on trading behavior, Khapko and Zoican (2017) analyze the importance of settlement times for market making incentives, and Hautsch, Scheuch, and Voigt (2018) examine the impact of the Bitcoin blockchain's stochastic settlement speed on the resolution of arbitrage.

Finally, when an ICO constitutes a presale of output, token financing is similar to crowdfunding. In contrast to an ICO, where tokens can be resold in a secondary market, with crowdfunding, the product is typically pre-sold only to future consumers (not investors) and therefore the funds raised during a crowdfunding campaign can serve as a signal about the uncertain demand. Li (2016) and Cimon (2016) describe how a presale to customers can help firms, who face high uncertainty concerning the demand, finance a project.

II. The Model

Entrepreneur and Investors. An entrepreneur seeks to raise money for a new venture. The venture provides a good or service, and the entrepreneur will be a monopolistic provider. There is a fixed set-up cost C_0. The demand for the new product is uncertain, and it will only be revealed after the set-up cost has been paid and the venture, for instance, a platform, has been set up.

In the benchmark model, the demand is exogenous; in the more general version, the entrepreneur is able to influence the demand at a (private) cost of effort, e.g., through more extensive marketing activities, active platform maintenance, platform choices that enhance usability or convenience, etc.

The entrepreneur does not have the funds to pay the set-up cost C_0, and must raise C_0 from outside investors and/or future users of the platform/service. We normalize the required rate of return to zero. Investors are risk-neutral, and they provide the funds as long as they break even in expectation.

In what follows, we refer to the entrepreneur in the female form, and we use the male form for investors.

Financing Options. The entrepreneur has a choice of two financing options. The first one is canonical equity financing, where investors provide funds in exchange for a share α_e of future profits. The second option is to raise funds by pre-selling the rights to the future product or service in an "initial coin, or token, offering" (ICO). With an ICO, an entrepreneur issues tokens that can and must be used to purchase the good or service. To raise funds, the entrepreneur may choose to pre-sell a fixed number of units of the future product, by offering t tokens, or a fixed share of the produced units, by selling a share α_t of all issued tokens to investors. We refer to the former arrangement as an *output presale*, and we refer to the latter arrangement as *revenue sharing*. Once the demand is realized and the good is produced, the token-holders are able to either obtain the good or to resell their tokens. We do not model the mechanics of the secondary market in this paper, and assume that investors are able to redeem their tokens at the market price for the good. One way to achieve this outcome would be a direct contract with the entrepreneur, whereby the latter commits to either deliver the good or to repurchase the token. As is typical for early stage financing, the entrepreneur has no access to credit markets.

We assume that there are no capital constraints and no asymmetric information. In our model, the venture will be financed, as long as its expected net present value is positive, given the choice of the financing. This is different to crowdfunding models of ICOs, where the funds are provided by future users not investors, and where the amount of funds raised serves as a signal about the future demand for the platform services.[10]

Product Supply and Demand. The entrepreneur will face a linear demand, with the inverse demand function for q units given by:

$$p(q) = x - q, \tag{1}$$

where x is realized after the set-up cost has been paid, and it is uniformly distributed on $(0, \theta)$. In the benchmark model, θ is independent of the entrepreneur's actions, whereas in the more general model, we assume that $\theta = \theta_h$ if the entrepreneur exerts effort and $\theta = \theta_l < \theta_h$ otherwise.

The entrepreneur is a monopolist and will be able to produce the good at a constant marginal cost c per unit.

Timing and Actions. At time zero, the entrepreneur chooses the financing method and obtains the funds. With equity financing, the entrepreneur raises exactly C_0 and invests the entire amount, as is common with VC financing. With ICO financing, the entrepreneur has more control over the funds and may choose to raise a larger amount, e.g.,

[10]See, for instance, Li (2016) or Cimon (2016).

to partly cover the marginal cost of production in addition to the fixed cost of financing.

At time one, the demand is realized and the entrepreneur chooses the production quantity that maximizes her profits, taking into account the contracts with investors and the demand realization.

III. The Impact of Financing Choices

In this section, we analyze the impact of the financing choices on the entrepreneur's production choices and profits, under the assumption of a fully exogenous demand.

A. Benchmark: Own Funds

As a benchmark, we first derive the entrepreneur's profits in the absence of possible agency conflicts, when she has sufficient funds to finance the venture. The fixed set-up cost must be paid up front, and it does not feature in the profit maximization problem at time one. For each realization of demand, she chooses quantity $q = q^m$ that maximizes the monopoly profits:

$$\pi^m(x) = q(x-q) - cq \quad \Rightarrow \quad q^m = \frac{x-c}{2} \text{ for } x \geq c \text{ and 0 otherwise.} \tag{2}$$

The entrepreneur's expected profits equal the project's expected net present value:

$$NPV = \int_c^\theta \frac{1}{\theta}\left(\frac{x-c}{2}\right)^2 dx - C_0 = \frac{1}{12}\frac{(\theta-c)^3}{\theta} - C_0. \tag{3}$$

When financing the venture with her own funds, the entrepreneur commits her funds if and only if the net present value defined in (3) is positive.

B. Equity Financing

With equity financing, the entrepreneur offers the equity investors the fraction α_e of the expected profits, such that investors break even in expectation. Upon observing the demand realization, the entrepreneur chooses quantity q to maximize:

$$\pi_e^m(x) = (1 - \alpha_e)(q(x - q) - cq) \tag{4}$$

The maximization problem is identical to one that arises when the entrepreneur uses her own funds, and the profit maximizing quantity remains the monopoly quantity q^m, defined in (3). Therefore, for the equity investors to break even, they demand fraction α_e of profits that solves:

$$\alpha_e \mathsf{E}[\pi^m(x)] = C_0 \quad \Rightarrow \quad \alpha_e = \frac{12\ \theta C_0}{(\theta - c)^3}. \tag{5}$$

The entrepreneur earns the venture's NPV, and the project can be financed as long as its NPV is positive.

C. ICO financing

In a token financing, the entrepreneur pre-sells some of the future output to the investors. Token-holders are not able to resell the good (e.g., because it's a service that the entrepreneur provides on her platform), but that they are able to sell their tokens at the good's prevailing market price.[11] Differently to equity financing, where contract terms are well-established, with token financing, the entrepreneur has several choices.

[11] Although token sales relate to crowdfunding, in crowdfunding, the good is pre-sold to users, whereas in token issuances, a re-sellable right to a good or service is sold.

She may choose to pre-sell a *fraction* α_t of the total number of units of the good or service that will be produced; we will refer to this arrangement as *revenue sharing*. Alternatively, she may choose to pre-sell a pre-determined *number of units* of the good or service, by issuing t tokens to the investors; we will refer to this arrangement as *output presale*. In this latter case, the entrepreneur must also choose the "bankruptcy" contract terms for the case where the realized demand is too low to profitably sell t units of the good or service at time one.

We next illustrate that the two ICO financing methods lead to different conflicts of interest between token-holders and the entrepreneur, and to different production choices. As the financing choices affect production decisions, the Modigliani-Miller capital structure irrelevance theorem does not apply, and the choice of ICO contract terms affects the entrepreneur's profits.

We first compare the entrepreneur's production choices when the realized demand is sufficiently high, and we will address the choice of the "bankruptcy" contract terms in the next subsection.

ICO financing option 1: Revenue sharing. We first consider the choice of pre-selling a fraction of output, similar to Chod and Lyandres (2018). There are several ways to achieve this from a technical perspective. The entrepreneur issues T tokens in total, sells fraction α_t of these to the investors, and retains the remainder. To provide fraction α_t of the output to the token-holders, the number of tokens required per unit of service is determined after the production decision has taken place: if the entrepreneur produces q units, each unit of good or service would require the payment of T/q tokens.

When issuing tokens, the entrepreneur may elect to raise more than C_0, in order to cover part of the marginal cost, but as these funds are raised ex ante, they do not depend on the quantity produced and do not affect the entrepreneur's production choice when the demand is sufficiently high.

The entrepreneur chooses to produce quantity q that maximizes:

$$\pi^e_{\text{token share}}(x,q) = (1-\alpha_t)q(x-q) - cq \quad \Rightarrow \quad q = \frac{x - c/(1-\alpha_t)}{2} < q^m. \tag{6}$$

Differently to equity financing, where the entrepreneur is entitled to a fraction of *profits*, with ICO financing, the entrepreneur retains a fraction of *revenues* while still paying the full marginal cost of production. Consequently, she chooses the production quantity such that the entrepreneur's share of the marginal revenue equals the entire marginal cost, and the total quantity produced is below the monopoly quantity q^m; we illustrate this issue in the left panel of Figure 1. This "underproduction," relative to the monopoly quantity, is similar to the underinvestment in Chod and Lyandres (2018). As the entrepreneur fails to maximize the venture's aggregate profits, the expected net present value of the project under the ICO revenue sharing arrangement is below the maximum expected net present value, and some profitable projects cannot be financed.

Lemma 1 (Revenue Sharing)**:** *ICO financing by pre-selling a share of the revenue leads to underproduction, relative to the profit-maximizing quantity. Consequently, some profitable projects cannot be financed by the ICO revenue sharing.*

ICO financing option 2: Output presale. An alternative to pre-selling a fraction of the output is to pre-sell a fixed number of units of the good or service. In this case, the entrepreneur will sell t tokens to investors, which would entitle them to t units of the future good or service.[12] Differently to the presale of a fraction of the output, here

[12]The number of tokens required per unit of good or service is immaterial, provided it is pre-set in advance, together with the "bankruptcy" terms for the case of insufficient demand. Our analysis is

the entrepreneur does not pre-commit in advance to the total number of tokens to be issued. Instead, her choice of the total number of tokens is linked to her production choice: if q units are to be produced, the entrepreneur will issue t tokens to investors at time zero and $q-t$ additional tokens to herself at time one, after the production choice has been made.

As with pre-selling a fraction of the output, the entrepreneur may raise additional funds to cover (some of) the marginal cost of production, but these funds do not affect the production choice when the demand is sufficiently high.

The entrepreneur chooses to produce quantity q that maximizes:

$$\pi^m_{\text{token number}}(x,q) = (q-t)(x-q) - cq \quad \Rightarrow \quad q = \frac{x+t-c}{2} > q^m. \tag{7}$$

Pre-selling a fixed amount of the output in an ICO leads to a very different type of agency conflict, compared to the presale of a revenue share. Specifically, when choosing the quantity, the entrepreneur fails to internalize the price impact that the production of an extra unit of output has on the token-holders. This externality leads to an "over-production," relative to the monopoly quantity. We illustrate this issue in the right panel of Figure 1.

Lemma 2 (Output Presale)**:** *ICO financing by pre-selling a fixed number of output units leads to overproduction by the entrepreneur, relative to the profit-maximizing quantity. Consequently, some profitable projects cannot be financed by the ICO output presale.*

Optimal ICO financing Our preceding discussion in this section illustrates that the method of token issuance affects the entrepreneur's production incentives. Offering

unaffected by the exchange rate, and variable t would denote the number of pre-sold units.

investors a fraction of the future revenue leads to under-production, relative to the monopoly quantity, while pre-selling a pre-determined amount of the output leads to over-production.

It is individually rational for the entrepreneur to seek a financing structure that incentivizes her to produce the monopoly quantity. Since investors always require a sufficient amount of tokens to break even in expectation, in the absence of further private costs, the entrepreneur's ex ante goal must be to maximize the venture's total profits. When choosing the terms of financing, she must therefore prefer a contract that would incentivize her to produce the monopoly quantity for each realization of demand.

We will now explain how ICO financing can be structured to incentivize the entrepreneur to choose a production level that is in the interest of the token-holders. Although neither of the ICO financing choices that we have discussed thus far delivers these incentives, a combination of them does.

An externality such as the one that arises in the output presale is traditionally addressed by imposing a tax. In this case, a tax on the entrepreneur's revenue in favor of the token-holders delivers the desired correction.

One way to implement the tax is through an appropriate token monetary policy: in addition to issuing t initial tokens to the investors, the entrepreneur commits to deliver fraction α_t of all the tokens to the original token-holders that are issued *after* the production decision.

Lemma 3 (Optimal revenue share)**:** *For each level $t > 0$ of the output presale, there exists a revenue share α_t such that the entrepreneur optimally chooses the profit- maximizing production quantity, when she receives fraction $(1 - \alpha_t)$ of all revenue in excess of the pre-sold t units.*

Proof of Lemma 3. If the original toker-holders receive revenue share α_t of post-production tokens, then the entrepreneur chooses to produce quantity $q = q_t$ that maximizes her profit:

$$\pi_t^e(x, q) = (1 - \alpha_t)(q - t)(x - q) - cq \quad \Rightarrow \quad q_t = \frac{x + t - c/(1 - \alpha_t)}{2}. \tag{8}$$

The quantity q_t equals the monopoly quantity q_m when the entrepreneur offers fraction

$$\alpha_t = \frac{t}{c + t} \tag{9}$$

of the post-production-decision tokens to the original token-holders. □

Provisions for low realized demand. There are two considerations that we have thus far ignored in our discussion of ICO financing. First, with a positive marginal cost, the entrepreneur must make positive profits in order to produce a positive quantity. Second, she must specify the "bankruptcy terms" for the case when the demand is too low and the output is below t units.

As token-holders break-even in expectation, the entrepreneur's goal when setting the financing terms is to maximize the venture's aggregate profits. The optimal financing contract would therefore require that the entrepreneur produces the monopoly quantity q^m, for each demand realization.

To achieve this, the entrepreneur must (i) raise sufficient funds to cover the marginal cost for the first t units, and (ii) commit the full output to the token-holders and refund the unused funds, if the quantity produced is below t.

Requirement (i) ensures that the entrepreneur produces a positive quantity as long as $q^m > 0$, even if her fraction of the revenues is below the full cost of production.

Requirement (ii) ensures that the entrepreneur does not have an incentive to over-produce for the case when $q^m \leq t$.

To see these two points, observe first that when the produced quantity q exceeds the number of the initially issued tokens t, the entrepreneur's profit is:

$$\pi_t^e(x,q) = \frac{c}{c+t}(q-t)(x-q) - c(q-t) = \frac{c}{c+t}(q-t)(x-q-c-t). \tag{10}$$

The entrepreneur's maximization problem here is identical to that in (8), and the profit-maximizing quantity is the monopoly quantity $q_t = q^m = (x-c)/2$.

Case 1: $q^m > t$. When quantity q^m exceeds t, the entrepreneur's profit in (10) is necessarily positive:

$$\pi_t^e(x,q^m) = \frac{c}{c+t}\left(\frac{x-c}{2} - t\right)^2 > 0, \tag{11}$$

and she chooses to produce q^m.

Case 2: $q^m \leq t$. When the monopoly quantity $q^m \leq t$, the entrepreneur earns zero profits by following the prescribed strategy of producing quantity q^m and disbursing the unused funds $c(t-q^m)$ back to the token-holders; the good or service is offered at t/q^m tokens per unit. Requirement (ii) ensures that the entrepreneur does not have an incentive to deviate from this strategy. In order for the entrepreneur to earn positive profits under (ii), she would need to produce quantity $q > t$. But any $q > t$ yields negative profits when $q^m = (x-c)/2 < t$:

$$\pi_t^e(x,q) \propto (x-q-c-t) < 2t-q-t = t-q < 0, \tag{12}$$

We summarize the entire discussion in the following proposition.

Proposition 1 (Profit-Maximizing ICO Financing)**:** *The following ICO financing contract maximizes the entrepreneur's expected profits:*

- *At time zero, t units of the good are pre-sold to investors at a total cost of $C_0 + ct$ for t tokens, where t solves:*

$$\frac{c}{c+t}\frac{2}{3\theta}\left(\frac{\theta-c}{2}-t\right)^3 = \frac{1}{12}\frac{(\theta-c)^3}{\theta} - C_0. \tag{13}$$

- *If the quantity q produced at time one exceeds t, existing token-holders receive fraction $\alpha_t = t/(t+c)$ of the newly issued tokens; otherwise they are able to redeem their tokens at a rate of t/q per unit and receive a refund of $c(t-q)$.*

The entrepreneur optimally produces quantity $q^m = (x-c)/2$ if the realized value of x that determines the demand exceeds c, and she produces 0 otherwise.

We derive condition (13) in the Appendix, where we also prove that there exists a unique value of t for the number of tokens that solves it. Observe that the right-hand side of (13) is the (maximum) net present value of the project, and the left-hand side is the expected profit to the entrepreneur. Condition (13) then simply states that the number of tokens issued under the optimal ICO contract terms is such that the entrepreneur receives the project's maximum expected net present value.

Corollary (Equivalence of financing)**:** *In the absence of further agency costs and frictions, all projects that have positive expected net present value can be financed by either equity or by an ICO. The entrepreneur receives the project's net present value in expectation, for either financing method.*

In the Appendix, we prove following proposition on the optimal number of tokens t

that the entrepreneur should issue at time zero.

Proposition 2 (Comparative Statics)**:** *The optimal number of tokens t that are presold to investors at time zero increases in the set-up cost C_0 and marginal cost c, and it decreases in the level of expected demand θ.*

With the exception of changes in the marginal cost c, when the number of tokens t increases, investors retain a larger share of the future revenues (since the revenue share is given by $c/(c+t)$).

IV. Financing with Moral Hazard

A key insight from the previous section is that revenue sharing, which is a key feature of ICO financing, generically distorts production incentives and leads to agency conflicts between the entrepreneur and token-holders. Consequently, with generic revenue sharing, the entrepreneur fails to make profit-maximizing choices, which in turn leads investors to demand larger amounts of tokens, lowers the entrepreneur's ex ante expected profits, and in some cases makes it impossible to finance profitable projects.

Proposition 1 illustrates that the conflicts of interest can be addressed and will disappear when the ICO financing contract is designed optimally, so that the entrepreneur is incentivized to maximize the venture's aggregate profits. The optimal ICO design involves a combination of a quantity presale and a revenue sharing arrangement. In the absence of frictions, an ICO financing contract can be designed to ensure that the entrepreneur retains the project's full NPV in expectation, so that the equity and ICO choices of financing are equivalent.

Under the optimal ICO contract, the entrepreneur obtains her profits through the sale of additional tokens, and she can only sell those tokens and earn positive profits if the demand is sufficiently high. This feature resembles debt-financing, because with debt, the entrepreneur first has to pay off her loans and earns a profit only when the demand is sufficiently high. In this section, we illustrate that the debt-like feature of ICO financing likewise makes it superior to equity finance.

Suppose that the entrepreneur is able to influence the demand by "exerting effort", for instance, through targeted marketing activities or by improving the platform's support and user-friendliness. Specifically, if she puts in effort, the inverse demand will be $x - q$, with x uniformly distributed on $(0, \theta_h)$; otherwise x is uniformly distributed on $(0, \theta_l)$ with $\theta_l < \theta_h$. Assume that the monetary cost of the effort-related improvements is zero, but that they reduce the value of the project to the entrepreneur by C_e, which we refer to the as the "cost of effort," e.g., because they require more of her time, more attention to detail, or more intense monitoring of employees. We assume that the entrepreneur chooses her level of effort after the financing contracts are signed, and that her level of effort is not verifiable and cannot be contracted upon.

For simplicity, assume that the project has a positive expected net present value only if the entrepreneur exerts effort. Further, assume that the expected NPV of the project, defined by (3), exceeds C_e for $\theta = \theta_h$.

When using her own funds, the entrepreneur always chooses to exert effort, as the project's expected NPV is negative otherwise. When financing the project, however, she compares her expected profits net of funds raised.

A. Effort under equity financing.

We first consider equity financing. Investors will only finance the project if, conditional on the terms of financing, the entrepreneur will choose to exert effort. Therefore, they require share α_e of equity such that they break-even when the demand is drawn from a distribution governed by the parameter $\theta = \theta_h$:

$$\alpha_e \, \frac{(\theta_h - c)^3}{12\theta_h} = C_0. \tag{14}$$

The entrepreneur exerts effort only if:

$$(1 - \alpha_e) \, \frac{(\theta_h - c)^3}{12\theta_h} - C_e \geq (1 - \alpha_e) \, \frac{(\theta_l - c)^3}{12\theta_l}. \tag{15}$$

Substituting the required equity share α_e from (14) into the entrepreneur's incentive constraint and re-arranging, the project can be financed by equity only if:

$$NPV_h - C_e \geq NPV_h \times \frac{\theta_h}{\theta_l} \left(\frac{\theta_l - c}{\theta_h - c} \right)^3, \tag{16}$$

where we use NPV_h to denote the expected NPV of the project in (3) for $\theta = \theta_h$. Observe that the right-hand side of the inequality (16) exceeds 0, and the incentive constraint is therefore binding. As a consequence, some projects that have positive expected net present value and that will be undertaken when the entrepreneur has own funds cannot be financed by equity.

B. Effort under optimal ICO financing.

We next examine whether the optimal ICO financing arrangement, described in Proposition 1, creates incentives that mitigate the moral hazard problem.

As with equity financing, investors provide funds only if the entrepreneur chooses to exert effort. The number of tokens that the entrepreneur issues at time zero therefore solves (13) for $\theta = \theta_h$:

$$\frac{c}{c+t}\frac{2}{3\theta_h}\left(\frac{\theta_h - c}{2} - t\right)^3 = NPV_h. \tag{17}$$

First, observe that the moral hazard problem does not arise if the optimal number of tokens t that solves (17) satisfies $2t \geq \theta_l - c$, because in this case the entrepreneur does not earn positive profits under the low demand distribution, and she will therefore exert effort. The moral hazard problem under the ICO financing terms of Proposition 1 therefore arises only when the number of tokens t is small: $2t < \theta_l - c$.

When t is small, $2t < \theta_l - c$, the entrepreneur exerts effort if:

$$\frac{c}{c+t}\frac{2}{3\theta_h}\left(\frac{\theta_h - c}{2} - t\right)^3 - C_e \geq \frac{c}{c+t}\frac{2}{3\theta_l}\left(\frac{\theta_l - c}{2} - t\right)^3. \tag{18}$$

Using the token-holders' break-even condition (17) and rearranging, the entrepreneur's incentive constraint (18) becomes:

$$NPV_h - C_e \geq NPV_h \times \frac{\theta_h}{\theta_l}\left(\frac{\theta_l - c - 2t}{\theta_h - c - 2t}\right)^3. \tag{19}$$

C. Comparing equity and ICO financing.

The incentive condition (19) is weaker than the corresponding condition (16) for equity financing, in the sense that whenever the incentive constraint for equity financing is satisfied, so is the condition for ICO financing — but the converse is not true:[13]

$$NPV_h \times \frac{\theta_h}{\theta_l}\left(\frac{\theta_l - c}{\theta_h - c}\right)^3 > NPV_h \times \frac{\theta_h}{\theta_l}\left(\frac{\theta_l - c - 2t}{\theta_h - c - 2t}\right)^3. \tag{20}$$

We summarize our results in the following proposition.

Proposition 3 (Equity vs. ICO financing with moral hazard)**:** *All projects that can be financed by the optimal ICO contract can also be financed by equity, but the converse is not true. In the presence of entrepreneurial moral hazard, some profitable ventures that can be financed through an ICO cannot be financed by equity.*

We next provide an example of a profitable project that can be financed by an optimal ICO contract, but that will be rejected by a venture capitalist because of the entrepreneurial moral hazard.

Example: when ICO financing beats equity. Consider an economy that is governed by the following parameters: the demand parameters are $\theta_h = 50$ and $\theta_l = 46$, the set-up cost $C_0 = 100$, the marginal cost $c = 10$, and the cost of effort to the entrepreneur is $C_e = 5/3$.

In this economy, the maximum expected profits for the project are:

$$\mathsf{E}[\pi_h] = \frac{1}{12}\frac{(\theta_h - c)^3}{\theta_h} = 106\frac{2}{3} \quad \text{and} \quad \mathsf{E}[\pi_l] = \frac{1}{12}\frac{(\theta_l - c)^3}{\theta_l} \approx 84.5. \tag{21}$$

The project's net present value is positive only for $\theta = \theta_h$, when the entrepreneur exerts effort. Further, the net present value for θ_h equals $20/3$, and it exceeds the entrepreneur's cost of effort. Therefore, if the entrepreneur had her own funds to cover the set-up cost, she would finance the project. We now consider external financing.

[13] To see this, note that $y/z > (y-t)/(z-t)$ whenever $y > z$ and $t > 0$.

First, suppose that the entrepreneur wishes to raise equity funds. In this case, investors would require a share of profits α_e such that $\alpha_e \mathsf{E}[\pi_h] = 100$. Solving the indifference condition, $\alpha_e = 15/16$. Fraction $1 - \alpha_e = 1/16$ of the venture's profits received by the entrepreneur is too small relative to her private cost of effort, and she would not exert effort in equilibrium:

$$(1 - \alpha_e)\mathsf{E}[\pi_h] - C_e = 5 < (1 - \alpha_e)\mathsf{E}[\pi_l] \approx 5.28. \tag{22}$$

Since the equity financiers do not break even when the entrepreneur exerts no effort, this particular, intrinsically profitable project cannot be funded by equity.

Second, consider ICO financing. The revenue-based ICO contract terms of Proposition 1 offer different incentives to the entrepreneur and will resolve the moral hazard problem in this case. Solving expression (13) for the optimal number of tokens t to issue to at time zero, we obtain $t = 10$. The profit-maximizing ICO contract prescribes that the entrepreneur pre-sells 10 units of the output to investors and offers them share $\alpha_t = t/(c+t) = 1/2$ of any further revenue when the entrepreneurs produces more than the 10 pre-sold units. Under these terms, the entrepreneur's payoff with effort exceeds that without effort:

$$\begin{aligned} \mathsf{E}[\pi \text{ with effort}] &= \frac{2}{3\theta_h}\frac{c}{c+t}\left(\frac{\theta_h - c}{2} - t\right)^3 - C_e = 5 && (23) \\ \mathsf{E}[\pi \text{ no effort}] &= \frac{2}{3\theta_l}\frac{c}{c+t}\left(\frac{\theta_l - c}{2} - t\right)^3 \approx 3.71. && (24) \end{aligned}$$

Consequently, the entrepreneur is incentivized to exert effort, the project can be financed, and the entrepreneur receives the project's net present value, in expectation.

V. Discussion and Conclusion

Undoubtedly, the initial coin and token offerings are fraught with problems: according to one estimate, almost 85% of all offered issuances are fraudulent.[14] Moreover, the very first token offering, the Ethereum network's DAO, contained a coding error that allowed a participant to extract the equivalent of 30 million U.S. dollars and that led to the split of the network into Ethereum and Ethereum Classic — not a good start. The boom in token issuances also occurred at the same time as the apparent bubble in crypto-currencies such as Bitcoin and Ether, and it has therefore and quite naturally, been attributed to irrational exuberance, the chasing of a bubble, or even money laundering and other illicit activities. At the same time, the traditional world of finance has strong incentives to discredit token offerings.[15]

A key *economic* question is whether tokens can fulfill new economic functions and whether they are able to address a problem that traditional tools fail to solve. In this paper, we make the case for tokens as a new financing tool that can be superior to traditional equity. Using ingredients from the standard toolbox of theoretical corporate finance and industrial organization, we show that within the context of our model, all projects that can be funded by equity can also be funded by a token contract that offers token holders rights to future revenues, instead of profits. Critically, however, when there is a moral hazard problem between the entrepreneur and the financiers, some profitable projects that cannot be funded by equity can be funded via a token offering, with a

[14] https://medium.com/satis-group/ico-quality-development-trading-e4fef28df04f; however, to the eco-system's credit, according to this article by the Satis Group, most of the fraudulent offerings never receive funds and never make it past the announcement stage.

[15] Powerful intermediaries have much to lose if token offerings emerge as a new standard for financing: the business models of venture capitalists and their investors, issuance departments of investment banks, and even of stock exchanges would all be fundamentally affected. Alas, the movie, music, and print industry as well the offline retail industry used to be powerful, too, once upon a time.

revenue-based dynamic contract.

Moral hazard concerns are a common issue for early-stage firms, and they are particularly relevant in the new decentralized world that blockchain enthusiasts seek funds to build. Financial industry insiders arguably have less expertise with the new blockchain-based economy than with "standard" tech firms, their advice and oversight may be less useful, and the moral hazard is therefore more severe.

More generally, revenue-based token offerings may provide opportunities for financially constrained existing firms that want to finance a new project. Once funds have been disbursed, financiers who use traditional forms of financing often cannot monitor whether their funds are used for a particular project. Where the ensuing moral hazard precludes traditional equity financing, a well-designed token contract that is tied to project-specific revenues may resolve the problem.

Our model provides a blueprint for revenue-based token offerings: the optimal compensation to token-holders should consist of both a presale of output units and a commitment to share revenues in the future. Optimal token contracts therefore have features of both debt and equity. Our insights are based on a parsimonious two-period model. As Catalini and Gans (2018) highlight, a typical token sale collects funds in return for only one round of revenue, whereas equity is "forever." Future work may explore repeated token sales, possibly under perpetual moral hazard problems. It may also be fruitful to study whether token offerings allow new approaches to profit and revenue sharing among stakeholders of commercial enterprises. Founders, engineers, and other employees may be paid directly in tokens, possibly allowing better alignment of their incentives with those of the firm than, for instance, stock options or stock ownership programs.

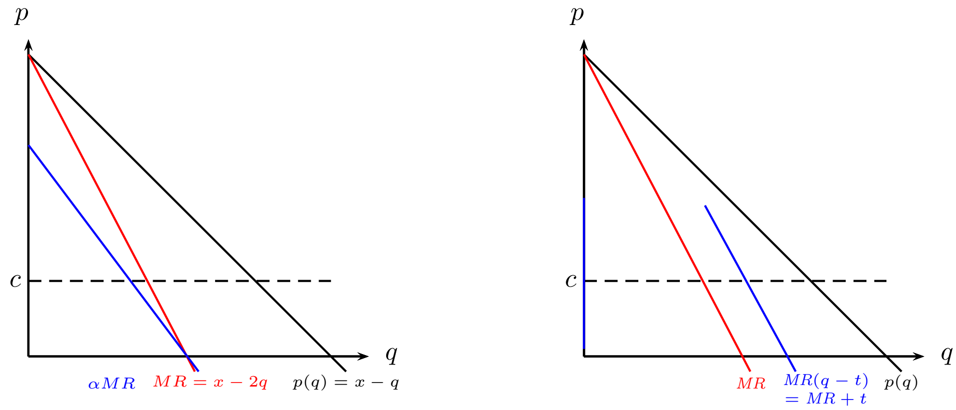

Figure 1

Quantity choices under revenue sharing and output presale

Both panels: The inverse demand function is $p(q) = x - q$, marginal revenue is $MR = x - 2q$. The monopoly quantity is the value q where the red line (marginal revenue) intersects with the dashed line, marginal cost, where $q^m = (x - c)/2$. The competitive quantity, which is not under consideration in this paper, is the intersection of the dashed line with the demand curve, the solid black line. *Left Panel: Revenue Sharing* The blue line, αMR is the entrepreneurs marginal revenue when sharing fraction α of revenues with investors. The entrepreneur chooses the quantity q^α where the blue line intersects with marginal costs, $q^\alpha = (x - c/(1 - \alpha_t))/2 < q^m$. *Right Panel: Output Presale* The blue line, $MR(q - t)$ is the entrepreneurs marginal revenue when pre-selling t units of output to investors. The entrepreneur chooses the quantity q^t where the blue line intersects with marginal costs, $q^t = (x + t - c)/2 > q^m$.

A Appendix: Proofs

Proof of Proposition 1. We have argued in text that the optimal ICO financing contract must combine the presale of a fixed number of tokens with future revenue sharing. Here, we show that investors break even in expectation when the number of tokens satisfies equation (13), and that there exists a unique value for the number of pre-sold tokens t that solves (13).

When the contract is structured as in Proposition 1, investors' compensation depends on the realized value of the demand. Specifically, they receive the following compensation:

- a refund of ct, when the realized value of x is below c (no production takes place);

- a refund of $c(t(x-c)/2)$ and the full monopoly revenue of $(x-c)(x+c)/4$, when $c < x < c+2t$;

- revenue $t(x+c)/2$ from the t tokens received at time zero and a share of the revenue from the time-one issued tokens $\frac{t}{c+t}(\frac{x-c}{2}-t)(x-\frac{x-c}{2})$ when $x > c+2t$.

For the investors to break even, the following condition must hold:

$$\begin{aligned} C_0 + ct &= \int_0^c \frac{1}{\theta} ct dx + \int_c^{c+2t} \frac{1}{\theta}\left(\frac{(x-c)(x+c)}{4} + c\left(t - \frac{x-c}{2}\right)\right) dx \\ &+ \int_{c+2t}^{\theta} \frac{1}{\theta}\left(\frac{t}{c+t}\left(\frac{x-c}{2} - t\right)\frac{x+c}{2} + \frac{t(x+c)}{2}\right) dx. \end{aligned} \tag{25}$$

Denoting the integrand in the last term by δ/θ, the term δ can be rewritten as:

$$\begin{aligned} \delta &= \frac{x-c}{2}\left(\frac{x+c}{2} - c\right) - \frac{c}{c+t}\left(\frac{x-c}{2} - t\right)\frac{x+c}{2} + c\left(\frac{x-c}{2} - t\right) + ct \\ &= \frac{(x-c)^2}{4} - \frac{c}{c+t}\left(\frac{x-c}{2} - t\right)^2 + ct. \end{aligned} \tag{26}$$

Re-arranging, the break-even condition (25) can be written as:

$$C_0 = \int_c^{\theta} \frac{(x-c)^2}{4\theta} dx - \int_{c+2t}^{\theta} \frac{1}{\theta}\frac{c}{c+t}\left(\frac{x-c}{2} - t\right)^2 dx. \tag{27}$$

Integrating (27), we obtain condition (13), which can be expressed as:

$$\frac{c}{c+t}\frac{2}{3\theta}\left(t - \frac{\theta - c}{2}\right)^3 + NPV = 0 \tag{28}$$

First, observe that there always exists $t \in (0, (\theta - c)/2)$ that solves (28): at $t = 0$, the left-hand side of (28) equals $-C_0 < 0$, and at $t = (\theta - c)/2$, the left-hand-side equals the project's $NPV > 0$. To show that t is unique, we re-arrange (28):

$$f(t) := \frac{t^3}{3} - t^2\frac{\theta - c}{2} + t\left(\frac{(\theta - c)^2}{4} + \frac{\theta}{2c}NPV\right) - \frac{\theta}{2}C_0 = 0. \tag{29}$$

Observe that $f(\cdot)$ is strictly increasing in t, since the derivative $f'(t)$ is a quadratic function with a positive first coefficient and zero real roots:

$$f'(t) := t^2 - t(\theta - c) + \left(\frac{(\theta - c)^2}{4} + \frac{\theta}{2c}NPV\right); \tag{30}$$

the determinant of the quadratic equation $f'(t) = 0$ is negative. Consequently, function $f(t)$ has a unique root t. $\square$

Proof of Proposition 2. Condition (13) that determines the optimal number of tokens can be written as:

$$F(c, C_0, \theta, t) := \frac{c}{c+t}\frac{2}{3\theta}\left(\frac{\theta - c}{2} - t\right)^3 - \frac{(\theta - c)^3}{12\theta} + C_0 = 0. \tag{31}$$

There exists a unique t that solves it, and it follows from the proof of Proposition 1 that function F is increasing in t. We can therefore use the Implicit Function Theorem to derive the comparative statics. Computing the partial derivatives with respect to t and C_0, we obtain:

$$\frac{\partial F}{\partial t} = -\frac{c}{(c+t)^2}\frac{2}{3\theta}\left(\frac{\theta - c}{2} - t\right)^3 - \frac{2c}{c+t}\frac{2}{3\theta}\left(\frac{\theta - c}{2} - t\right)^2 < 0 \tag{32}$$

$$\frac{\partial F}{\partial C_0} = 1 > 0 \tag{33}$$

Denoting by t^* the optimal number of tokens, by the Implicit Function Theorem:

$$\frac{dt^*}{dC_0} = -\frac{\partial F/\partial C_0}{\partial F/\partial t} > 0. \tag{34}$$

Computing the derivative with respect to the marginal cost c and rearranging:

$$\frac{\partial F}{\partial c} = \frac{2t}{3}\frac{(\frac{\theta-c}{2}-t)^3}{(c+t)^2\theta} + \left(\frac{(\theta-c)^2}{4\theta} - \frac{c(\frac{\theta-c}{2}-t)^2}{(c+t)^2\theta}\right) > 0, \tag{35}$$

where the inequality follows because (i) the first term is positive, and (ii) the sum in parentheses is 0 at t=0 and it increases in t. Consequently, $dt^*/dc > 0$. Finally, computing the derivative with respect to the level of demand θ and rearranging:

$$\frac{\partial F}{\partial \theta} = \frac{c}{3}\frac{(\frac{\theta-c}{2}-t)^2(2\theta+c+2t)}{(c+t)\theta^2} - \frac{(\theta-c)^2(2\theta+c)}{12\theta^2} < 0, \tag{36}$$

where the inequality follows because $\partial F/\partial\theta = 0$ at $t = 0$ and it decreases in t:

$$\frac{\partial}{\partial t}\left(\frac{\partial F}{\partial \theta}\right) = -\frac{c}{3}\frac{(\theta-c-2t)(2\theta+c+2t)}{(c+t)\theta^2} - \frac{c}{12}\frac{(\theta-c-2t)^2(2\theta-c)}{(c+t)^2\theta^2} < 0. \tag{37}$$

Consequently, $dt^*/d\theta < 0$.

B Appendix: Tokens vs. Coins

There is no established, generally accepted classification of tokens vs. coins, and in the public debate the terms are often used interchangeably. Our view is that coins relate to blockchain assets whose main purpose is to be to process general payments and that usually are intrinsic to a blockchain: examples are Bitcoin, Ether, Monero, ZCash, Lumens, and so on. A token, in our view, is a digital asset that builds on or uses an existing blockchain; these tokens, too, can be used for payment, but they are usually tied to specific services (e.g., file storage), in which case they are commonly referred to as *utility* tokens. Tokens can also signify ownership of physical assets such as real estate. Most tokens currently run as so-called smart contracts on the Ethereum blockchain, but some are also linked to the Bitcoin network (usually as so-called "coloured coins" (Lykke's token LKK is an example). The model in this paper primarily describes utility tokens. Another recent innovation are so-called stablecoins, which are tokens that a pegged to a fiat currency, e.g., Tether (USDT). Our paper does not apply to such tokens. In our paper, we use the term ICO (initial coin offering) to describe a token offering.

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