Optimal Financing with Tokens*

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Abstract

We develop a unifying model of the optimal issuance and design of tokens in the presence of frictions typical to the financing of digital platforms, such as the need to raise outside funds to finance platform development and the ensuing agency conflicts between platform developers and outsiders. Tokens possess utility features when they serve as the transaction medium on the platform. They possess security features when they distribute dividends. The paper shows how the optimal provision of utility and security features relates to financing needs, moral hazard, and platform characteristics and specifies the conditions under which initial coin offerings or security token offerings are optimal for platform financing.

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1 Introduction

Initial coin offerings (ICOs) have become an important source of financing for firms that develop digital platforms (Howell, Niessner, and Yermack (2019)). By the end of 2018, over 5500 firms had attempted to raise funds using an ICO, raising over 30 billion dollars (Lyandres, Palazzo, and Rabetti (2019)) and with at least 20 ICOs taking in more than 100 million dollars (Howell et al. (2019)). In an ICO, a firm raises funds by issuing cryptographically secured tokens. Because these tokens serve as the means of payment on a platform or offer access to the firm's services, they possess *utility features* and are therefore often called *utility tokens*. Despite the popularity of ICOs and the considerable growth of the academic literature on this new form of financing, a number of key questions remain open. Chief among these is whether an ICO should be preferred to alternative ways of financing, such as financing with equity or with tokens other than utility tokens, when funding a platform. Another related question is what explains the large and puzzling variation in the observed designs of tokens.

Tokens indeed come in many different forms. Many tokens only possess utility features and do not have any security features, such as cash flow or dividend rights. This is the case for example for the tokens issued in the ICOs of Filecoin or Golem. Symmetrically, several tokens—such as the LDC Crypto token or the BCAP token—do not possess utility features and resemble traditional securities, except that they are recorded and exchanged on a blockchain. Tokens with security features are classified by the so-called Howey Test as securities.[1] These tokens are called *security tokens* and sold in security token offerings (STOs). Remarkably, many tokens exhibit both utility and security features. For instance, multiple crypto-exchanges—such as Binance, BitMax, or KuCoin—feature tokens that are used to trade on the exchange and additionally allow token holders to earn income related to the overall transaction volume.[2] Peer-to-peer (P2P) lending platforms—such as Nexo, Ehtlend, or Bancera—have issued tokens of a similar type. Likewise, cryptocurrencies with proof-of-stake consensus algorithms—such as NEO, Cardano, or Ethereum after its Casper Protocol —both facilitate transactions and generate income to token holders.[3]

This paper develops a unifying model that nests these different types of tokens and studies the

[1] According to the Howey test, an investment contract is a security if the following four conditions hold: 1) it is an investment of money, 2) in a common enterprise, 3) with an expectation of profit, 4) with profit generated by a third party. Conditions 1 and 2 are typically satisfied for any type of token offering; conditions 3) and 4) are satisfied for example if the token distributes dividends.

[2] While Binance distributes profits to token holders through buybacks (i.e., token burning), KuCoin and BitMax explicitly pay dividends to token holders. In addition, transacting with the native exchange token offers fee discounts.

[3] Token holders are rewarded for staking (i.e., holding) tokens. Ethereum will switch to a proof-of-stake consensus algorithm after the so-called Casper Protocol (Buterin and Griffith (2017)) is implemented.

optimal token design in the presence of frictions that generally prevail in firms developing digital platforms, such as the need to raise outside funds to finance firm growth and the ensuing agency conflicts between insiders (platform developers) and outsiders. Specifically, we develop a model in which a startup firm, owned by penniless developers, builds a platform that facilitates P2P transactions among users. As in Cong, Li, and Wang (2019b,c), the platform features network effects that imply complementarities in users' endogenous adoption and transaction decisions. In addition, the platform generates cash flows that increase in the level of platform adoption (i.e., the platform transaction volume) and arise e.g., from transaction fees, advertisement proceeds, and/or from utilizing transaction data.

Entities conducting token offerings tend to have unproven business models and are most often in the pre-product stage (Fahlenbrach and Frattaroli (2019)). To capture these key features, we consider that the platform is initially not fully developed and that the startup firm has financing needs in that developers lack the funds to finance platform development. To raise the necessary funds, the startup can issue equity and/or tokens that may serve as the transaction medium on the platform and thus may exhibit *utility* features. These tokens may also exhibit *security* features, in that they may pay dividends in relation to platform cash flows. In addition to financing needs, platform development is subject to moral hazard. Specifically, the success of the platform depends on developers' hidden effort, which comes at a cost to developers.

In the model, developers' revenues stem from selling tokens to platform users and from the ownership of the startup equity, which is a claim on the cash flows that the platform generates. Users' motive to hold tokens and the pricing of tokens reflect both the token utility and security features, with an equilibrium token price that increases with the level of platform adoption. Token security features affect users' platform adoption decisions and, therefore, the value of the platform and of its native tokens. Because they grant cash flow rights to token holders, security features also reduce the value of developers' equity in the startup firm and undermine their incentives, which are determined by their equity ownership and by the tokens they retain. Crucially, equity and token incentives not only differ in their strength but also in their relationship with the token design. The paper solves for the optimal token design in this environment characterized by financing needs and moral hazard and derives the following main findings.

First, we demonstrate that issuing tokens is the optimal way to finance the startup in that financing with any other security, such as equity or debt, reduces both developers' payoff and the value of the platform. We then characterize the optimal token design and the provision of token utility and security features. Remarkably, token security features trigger endogenous network effects and spur platform adoption but their provision is affected by moral hazard and financing needs. Specifically, granting cash flow rights to token holders improves the return to holding tokens and therefore boosts the platform transaction volume. This, in turn, raises the platform's cash flows, which implies even more transactions and dividends. However, token security features dilute developers' equity ownership in the startup firm. Because the incentives generated by each dollar of equity ownership are stronger than the incentives from a dollar of token ownership, token security features undermine incentives. As a result, the optimal level of cash flow rights granted to token holders decreases in the extent of moral hazard. Since the under-provision of security features reduces platform adoption and value, moral hazard intensifies financing constraints. Symmetrically, larger financing needs imply that developers retain fewer tokens, thereby exacerbating the moral hazard problem. Financing needs and moral hazard thus reinforce each other, leading to low levels of token security features and token retention. We also show that moral hazard is more severe when network effects are low, the platform development phase is long, or when token velocity is excessively low or high, which induces low levels of security features and token retention.

Second, we analyze when issuing a utility token without security features is optimal. That is, we analyze when developers prefer an initial coin offering over a security token offering. An ICO is the optimal funding model if the platform value derives from facilitating transactions rather than from generating cash flows. An ICO is also preferable to a security token offering if financing needs, agency frictions, or the platform development phase are large. Thus, while the ICO funding model is often criticized on the basis that many firms have not yet delivered on their product, our analysis suggests to the contrary that projects with a long development phase are particularly suitable for conducting an ICO. Moreover, our model implies that startups with innovative business models, which are particularly prone to moral hazard, optimally raise funds via ICOs, consistent with Fahlenbrach and Frattaroli (2019) or Howell et al. (2019).

Third, we examine when a security token without utility features—that resembles conventional equity—is optimal. When tokens do not have utility features, fiat money is used as the platform transaction medium. Ceteris paribus, the ability to transact with fiat money reduces the cost of transacting for users and increases both the transaction volume and platform earnings. Intuitively, users are more willing to transact with fiat money as they do not bear crypto-related transaction costs. However, issuing tokens without utility features may constrain developers' ability to raise funds and harm platform success, notably, when platform value mostly comes from facilitating transactions among users. A token without utility features is therefore only optimal if platform cash flows are large or if network effects are strong. Taking stock, we find that—holding platform value constant—platforms with low cash flows are optimally financed by issuing tokens without security features, platforms with intermediate cash flows by issuing tokens with both utility and security features, and platforms with large cash flows by issuing tokens without utility features.

Fourth, we study the relation between token design and platform transaction (i.e., user) fees. Developers set transaction fees dynamically to maximize the startup's revenues but generally cannot commit to a fee structure. Cash flow rights granted to token holders allow developers to charge transaction fees without hampering adoption. At the same time, combining high levels of token security features and transaction fees implies a high token dividend yield, which triggers purely return-driven token investments and therefore crowds out transaction-based investments and harms platform adoption. As a result, the optimal level of transaction fees is lowest for both high and low levels of token security features. Our findings provide a rationale for the ICO funding model by showing that issuing a utility token serves as a commitment device to low transaction fees. We also show that the startup optimally subsidizes the user base to accelerate platform adoption when network effects are strong or when the blockchain technology facilitates developers' commitment.

Finally, we examine the asset pricing implications of token utility and security features. We show that while token security features spur platform adoption, they also amplify token price volatility. The reason is that security features generate endogenous network effects that increase the sensitivity of platform adoption to productivity shocks. This boosts the token price volatility because the token derives its value from the level of platform adoption. The effects of security features on the token price volatility are larger when the token possesses more utility features or when network effects are stronger. Thus, according to our model, the combination of token utility and security features causes particularly volatile token prices. Because there are many benefits of having a stable transaction medium (see e.g. Doepke and Schneider (2017)), our model also implies that security features embedded in a transaction token should not be excessive.

Our work is related to the literature on blockchain economics, tokenomics, and cryptocurrencies. Notable contributions include Athey, Parashkevov, Sarukkai, and Xia (2016), Abadi and Brunnermeier (2018), Makarov and Schoar (2019), Liu and Tsyvinski (2019), Cong and He (2019), Cao, Cong, and Yang (2019), Huberman, Leshno, and Moallemi (2019), Biais, Bisiere, Bouvard, and Casamatta (2019), Cong, He, and Li (2019a), Prat and Walter (2019), Saleh (2019), Pagnotta (2018), Easley, O'Hara, and Basu (2019), and Hinzen, John, and Saleh (2019). A review of this rapidly evolving research area is provided by Chen, Cong, and Xiao (2019).

A large subset of this literature focuses on ICOs with many empirical papers studying determinants of ICO success or documenting post-ICO patterns. Important contributions include Howell et al. (2019), Fahlenbrach and Frattaroli (2019), and Lyandres et al. (2019). Many firms issuing tokens develop a decentralized platform that promises network effects. Much of the theoretical literature on ICOs highlights the coordination benefits inherent to utility tokens; see e.g. Li and Mann (2018), Sockin and Xiong (2018), and Catalini and Gans (2018). Further theories on ICOs include Chod and Lyandres (2018), Chod, Trichakis, and Yang (2019), Goldstein, Gupta, and Sverchkov (2019), Holden and Malani (2019), Lee and Parlour (2018), Lyandres (2019), Malinova and Park (2017), and Mayer (2019). In contrast to these papers, our model is not limited to utility tokens but encompasses a richer class of tokens. In addition, we study the effects of financing needs and moral hazard on token design, while most research to date takes the token and platform design as exogenously given. For a literature review on ICOs, we refer to Li and Mann (2019).

Our paper also advances the literature on the economics of platforms. Early contributions in this literature, such as Rochet and Tirole (2003), do not consider tokens. More recently important progress has been made on platform finance with tokens. Notably, Cong et al. (2019c) analyze the pricing implications of users' inter-temporal adoption decisions. Cong et al. (2019b) connect tokenomics to corporate finance, with a focus on optimal token-supply policy to finance investment in platform quality. While we employ a similar modelling of users' platform adoption decisions, our paper differs from Cong et al. (2019c,b) in several important dimensions. First, Cong et al. (2019c,b) do not consider tokens with dividend rights and security features. Second, while Cong et al. (2019b) features conflicts of interest between users and developers, they abstract from moral hazard and platform financing needs which are the key frictions we model in this paper.

The paper is structured as follows. Section 2 presents the model. Section 3 solves the model. Sections 4 and 5 analyze the model implications. Section 6 introduces transaction fees. Section 7 introduces persistent productivity shocks. Section 8 concludes. All proofs and technical developments are gathered in the Appendix.

2 Baseline Model

Time is continuous and defined over $[0, \infty)$. There are two types of agents: developers and a unit mass of platform users indexed by $i \in [0, 1]$. All individuals are risk neutral and discount future payoffs at rate $r > 0$. Developers run a startup firm that launches a digital platform but lack the capital to develop it. They obtain funds at time zero by issuing tokens. Tokens serve as the transaction medium on the platform. They are in fixed unit supply and possess equilibrium price P_t (determined below). In addition, they are perfectly divisible, reflecting the fact that crypto tokens can generally be traded in fractional amounts. We conjecture and verify that token-based financing always dominates financing with any other security, such as equity. In particular, developers (optimally) do not issue outside equity and always own 100% of the startup's equity.

Platform Transactions. The platform allows users to conduct peer-to-peer transactions. As in Cong et al. (2019b,c), any user i has transaction needs and derives a utility flow

$$A_t N_t^{\chi} \, \frac{x_{it}^{\eta}}{\eta} \tag{1}$$

from a transaction of x_{it} dollars on the platform.[4] The utility derived from the transaction is concave in x_{it} and we employ the commonly used CRRA specification with $\eta \in (0, 1)$. The coefficient A_t is the platform productivity, which characterizes the usefulness of the platform. The specification in (1) captures network effects in that any user's utility from transacting increases in the volume of platform transactions N_t. That is, the higher the transaction volume, the easier it is to find a transaction counterparty and the more valuable it becomes to join the platform. The parameter $\chi \in [0, 1 - \eta)$ characterizes the strength of these network effects.

Transacting on the platform is costly. First, any user has to hold x_{it} dollars in tokens (or x_{it}/P_t tokens) for vdt units of time in order to transact.[5] Holding tokens is therefore costly because it implies a foregone opportunity to invest and earn interest for vdt units of time. The parameter $v > 0$ captures potential delays in settlements, in acquiring tokens or in finding an appropriate counter-party.[6] Second, in addition to these holdings costs, users incur direct costs of transacting $\phi x_{it} dt$ for a transaction of size x_{it} on the platform, where $\phi > 0$. This direct cost captures for instance transaction fees charged by miners or crypto-exchanges or a physical cost of platform operation that is charged to users. This direct cost may also be related to the effort and attention required for transacting on the platform, as in Cong et al. (2019c).

[4] This utility flow can be micro-founded by a random search and matching protocol; see Cong et al. (2019b,c).

[5] Appendix E provides a micro-foundation for this holding period. Cong et al. (2019b,c) assume that $v = 1$. Our specification allows us to analyze pure security tokens that do not have transaction value, which requires $v = 0$.

[6] Because, in practice, blockchain protocol and settlement latency (Easley et al. (2019), Hautsch, Scheuch, and Voigt (2019)) limit the influence that developers have on v, we treat it as an exogenous parameter. For example, transactions on the Bitcoin blockchain cannot occur instantaneously since a new block has to be created for the transaction settlement which takes, on average, 10 minutes.

Cash Flows. Once developed, the platform generates cash flows

$$dD_t = \mu(A_t)N_t dt, \tag{2}$$

where $\mu(A_t)$ is the platform cash flow rate. In practice, platforms may generate cash flows with advertisement proceeds, transaction fees, and/or by selling/using user data. Naturally, cash flows increase in the transaction volume N_t, platform productivity A_t, and the transaction fees ϕ. Therefore, we allow the cash flow rate $\mu(A_t)$ to depend on the platform productivity A_t with $\frac{\partial \mu(A)}{\partial A} \geq 0$. For analytical tractability, we assume that cash flows are linear in the transaction volume N_t and that there is no direct link between $\mu(A_t)$ and ϕ in that $\frac{\partial \mu(A)}{\partial \phi} = 0$. Under this assumption, the cost ϕ is a dead-weight loss as in, e.g., Cong et al. (2019c). In sum, platform cash flows increase in both platform productivity and transaction volume. This captures the idea that a more useful platform implies a higher user activity on both the extensive and intensive margins, which in turn raises the profits that platform operators extract, e.g., by setting (per-transaction) fees or selling user data. Section 6 incorporates endogenous transaction fees charged by platform developers to users and analyzes their effects on dividends, token design, and platform adoption and value.

Platform Development: Moral Hazard and Financing. Firms conducting token offerings are young and most often in the pre-product stage (Howell et al. (2019)). To capture this feature, we consider that the platform is developed over some time period $[0, \tau)$ and launched at time τ once a milestone has been reached. The arrival time of the milestone τ is governed by a Poisson process M_t with constant intensity Λ, so that over each time interval of length dt there is a probability Λdt that the platform development is complete and the expected time to development is $\frac{1}{\Lambda}$.

Platform development is subject to moral hazard and financing needs. Moral hazard arises because the success of the platform depends on developers' hidden effort $a_t \in \{0, 1\}$ which comes against a flow cost κa_t to developers, with $\kappa \geq 0$. Specifically, in case the milestone is reached over the time interval $[t, t + dt)$, the platform is successful only if developers exert effort over $[t, t + dt)$. Formally, we have that $A_s = 0$ for $s < \tau$ and

$$A_s = A_L + (A_H - A_L)\mathbf{1}_{\{a_\tau = 1\}} \tag{3}$$

for $s \geq \tau$, where developers have to choose effort a_t before the random event $dM_t \in \{0, 1\}$ realizes over $[t, t+dt)$. This modelling of productivity shocks is also employed in, e.g., Board and Meyer-ter

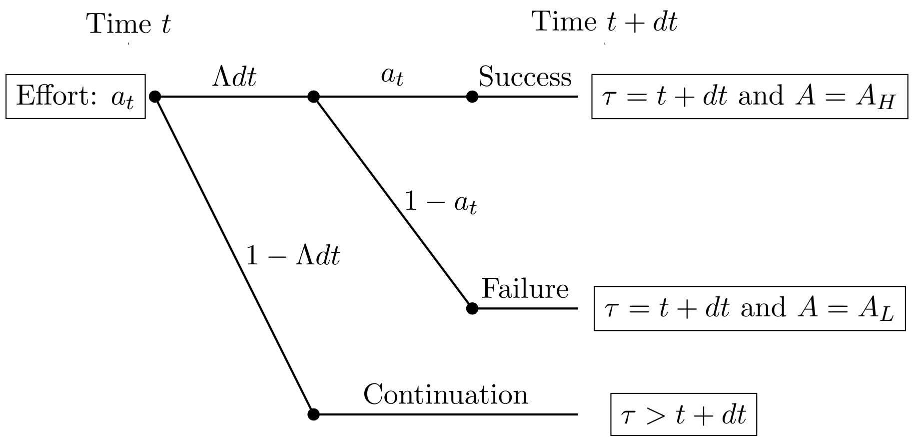

Figure 1: Heuristic Timing over $[t, t+dt)$. The branches of the tree contain the probabilities of the respective random event over $[t, t+dt)$.

Vehn (2013) and Hoffmann and Pfeil (2019). It follows that moral hazard is severe when the cost of effort κ or the expected time to development $1/\Lambda$ is large. Define $\mu_j = \mu(A_j)$ for $j \in \{H, L\}$. Figure 1 shows the timing of events over a time interval $[t, t+dt)$. For simplicity, platform productivity is constant after time τ. We study the implications of productivity shocks arising after time τ in Section 7 and show that this assumption has no bearing on our key findings.

In addition to moral hazard, the startup firm faces financing needs in that platform development requires investing $I \geq 0$ and developers do not have the capital to cover these needs. At inception, developers thus sell $1 - \beta_0$ tokens to the market and raise $(1 - \beta_0)P_0$ dollars. This token issue must be sufficient to cover the funding needs of the firm, leading to the constraint:

$$(1 - \beta_0)P_0 \geq I. \tag{4}$$

Developers cannot divert cash for their private benefit in that the funds raised at time zero are optimally invested in platform development or paid out as dividends.

Developers have incentives to exert effort because they hold tokens and own the firm's equity. While providing the funds necessary to finance platform development, token issuance also leads to a potential dilution of developers' stake in the firm, triggering moral hazard. Notably, developers initially retain $\beta_0 \in [0, 1]$ tokens that are only optimally sold when the milestone is reached at time τ. That is, developers sell $1 - \beta_0$ tokens at time zero and β_0 tokens at time τ. We emphasize that we do not restrict developers to this particular token trading behavior. Because the only productivity shock realizes at time τ, there is simply no reason to trade at any other time $t \notin \{0, \tau\}$.

Security features. Besides having utility features by serving as a transaction medium, tokens may also have security features in that they may pay a fraction $\alpha \in [0, 1]$ of total cash flows dD_t as a dividend to token holders, with the balance $(1-\alpha)dD_t$ being paid out as a dividend to the startup equity holders. Therefore, even though developers own 100% of the startup's equity, a token with $\alpha > 0$ dilutes developers' cash flow rights and the value of their equity ownership in the startup.

In summary, token utility features are represented by the convenience yield in (1). Token security features are captured by the token dividends αdD_t. In practice, the Howey test would classify any token with cash-flow rights as security, so that we refer to tokens with $\alpha > 0$ as security tokens. Conversely, when $\alpha = 0$, the token is a utility token and does not possess security features. That is, our model encompasses initial coin offerings as a special case in which $\alpha = 0$. There is an ongoing debate on whether utility tokens are securities. In classifying tokens as securities, our paper follows recent practice. In particular, tokens without cash flow rights (i.e., with $\alpha = 0$) are typically not classified as securities and, therefore, referred to as utility tokens.

Users' Adoption Decisions. Before the platform is developed at time τ, tokens do not offer transaction benefits. Consequently, tokens are fairly priced by ordinary risk-neutral investors/users implying that expected capital gains, $\mathbb{E}[dP_t]$, and dividends, $\mathbb{E}[\alpha\, dD_t]$, alone offer the investors the required return, $rP_t\, dt$:

$$\mathbb{E}[dP_t + \alpha\, dD_t] = rP_t\, dt \quad \text{for} \quad t < \tau. \tag{5}$$

After time τ, the platform is developed and holding x_{it}/P_t tokens over a time period of length $v\, dt$ generates additional transaction benefits and costs:

$$dR_{it} := \underbrace{A_t N_t^{\chi} \frac{x_{it}^{\eta}}{\eta} dt}_{\substack{\text{Convenience}\\ \text{yield}}} - \underbrace{x_{it}\phi\, dt}_{\substack{\text{Transaction}\\ \text{cost}}} + v x_{it}\left(\underbrace{\frac{dP_t}{P_t}}_{\substack{\text{Capital}\\ \text{gains}}} + \underbrace{\frac{\alpha\, dD_t}{P_t}}_{\substack{\text{Dividend}\\ \text{yield}}} - \underbrace{r\, dt}_{\substack{\text{Funding}\\ \text{cost}}} \right). \tag{6}$$

Equation (44) shows that by holding tokens and transacting on the platform, users realize both a convenience yield and capital gains. A transaction of size x_{it} comes at an effective cost $(vr + \phi)x_{it}$ that consists of the (funding) costs of holding tokens and the direct transaction costs.

The optimal transaction volume x_{it} of user i maximizes the expected utility flow at each point in time:

$$\max_{x_{it} \geq 0} \mathbb{E}[dR_{it}].$$

This yields that

$$x_{it}^{1-\eta} = \frac{A_t P_t N_t^{\chi} dt}{\phi P_t dt + v\big(r P_t dt - \mathbb{E}[dP_t + \alpha\, dD_t]\big)}. \tag{7}$$

All users $i \in [0, 1]$ face the same trade-off when determining the optimal size of their transaction. We thus have $N_t = \int_0^1 x_{it} di = x_{it}$ so that the transaction volume at time $t \geq \tau$ satisfies

$$N_t = \left(\frac{A_t P_t\, dt}{\phi P_t dt + v\big(r P_t\, dt - \mathbb{E}[dP_t + \alpha\, dD_t]\big)} \right)^{\frac{1}{1-\xi}}, \tag{8}$$

where we define for convenience $\xi := \chi + \eta$ as the transformed network effects parameter. A higher value of N_t means that each user is more active on the platform. As a result, the transaction volume N_t captures the degree of *platform adoption* at time t.

Developers' Problem. Developers choose effort a_t, their token holdings β_t, and the cash flow rights α attached to tokens. When tokens possess cash flow rights, developers receive $1 - \alpha + \beta_t \alpha$ dollars for each dollar of cash flows produced by the firm. Developers can sell their initial allocation of tokens at the prevailing market price. Accordingly, their optimization problem can be written as

$$V_0 = \max_{\alpha, \{\beta_t\}, \{a_t\}} \mathbb{E}\left[\int_0^{\infty} e^{-rt} (-P_t\, d\beta_t + (1 - \alpha + \alpha\beta_t) dD_t - \kappa a_t dt) \right] - I, \tag{9}$$

subject to the financing constraint (4).

3 Equilibrium and Model Solution

We study a *Markov Perfect Equilibrium.*

Definition 1. *In a Markov Perfect Equilibrium, the following conditions must be satisfied:*

1. *All individuals act optimally: Users maximize*

$$w_i := \max_{\{x_{it}\}} \mathbb{E}\left[\int_0^{\infty} e^{-rt} dR_{it} \right]. \tag{10}$$

   and developers solve (9).

2. *The token market clears before the milestone in that (5) is satisfied for all $t < \tau$.*

3. The token market clears after the milestone in that for all $t \geq \tau$:

$$\frac{v}{P_t}\left(\int_0^1 vx_{it}di\right) = \frac{vN_t}{P_t} \leq 1 - \beta_t. \tag{11}$$

If and only if the inequality (11) is strict, (5) holds for $t \geq \tau$.

The left-hand side in the market clearing condition (11) represents the token demand for transaction reasons. The right hand side represents the token supply. The token demand for transaction reasons is the product of the transaction volume N_t/P_t measured in units of tokens and the duration of the token holding period v. Intuitively, if v is large, users from previous transaction periods need to hold tokens in the current period, thereby increasing demand. (Appendix E discusses market clearing in more detail.) Lastly, if the token demand for transaction reasons is below the token supply, tokens must be held solely for their dividend rights and their price is determined by (5).

In the following, we solve the model before and after the milestone separately for any choice of $\alpha \in [0, 1]$ and $\beta \in [0, 1]$. Based on the model solution, one can then determine the optimal share α of dividends to token holders and the optimal level of token retention β.

3.1 Model Solution after the Milestone

We solve the model for any outcome $j \in \{H, L\}$. Since all uncertainty is resolved after time τ, it follows that all quantities remain constant at levels $X_j = X_t$ for all $t \geq \tau$ for $X \in \{P, N\}$ in that $dP_t = 0$ for all $t \geq \tau$. We incorporate uncertainty after time τ in Section 7, where we discuss the asset pricing implications of token utility and security features.

Because of their utility benefits, tokens are more valuable for users than for developers after time τ. In addition, there is no moral hazard problem once the platform has been launched. As a result, there is no value for developers in retaining tokens after time τ. Thus, developers sell all retained tokens at time τ so that $\beta_t = 0$ for all $t \geq \tau$. This implies that the value of developers' stake in the startup firm at time τ is equal to the value $\frac{(1-\alpha)\mu_j N_j}{r}$ of the startup's equity, where the price and transaction levels remain constant at levels P_j and N_j respectively.

Next, we derive the token price. Users may hold tokens for transaction purposes and/or because of their dividends. If dividends $\alpha\mu N_j$ exceed the funding cost rP_j, then users hold tokens purely for investment motives and the token price is given by the present value of its dividend rights:

$$P_j = \frac{\alpha\mu_j N_j}{r}.$$

In this case, the token is priced according to its *security features.* Otherwise, the token is held for transaction purposes and priced according to its *utility features.* In this case, N_j/P_j tokens are held over a period with length vdt. It follows that the effective token demand over a short period of time $[t, t+dt)$ is then given by vN_τ/P_τ. Token supply for $t \geq \tau$ is given by $1-\beta_t = 1$. Market clearing therefore implies that:

$$P_j = vN_j.$$

Combining the two cases, we obtain that the user base in equation (8) simplifies to

$$N_t = N_j(\alpha) = N_j = \left(\frac{A_j}{\max\{0, vr - \alpha\mu_j\} + \phi}\right)^{\frac{1}{1-\xi}} \tag{12}$$

and the token price is given by

$$P_t = P_j = \begin{cases} v\left(\frac{A_j}{vr-\alpha\mu_j+\phi}\right)^{\frac{1}{1-\xi}} & \text{if} \quad vr > \alpha\mu_j \\ \frac{\alpha\mu_j}{r}\left(\frac{A_j}{\phi}\right)^{\frac{1}{1-\xi}} & \text{if} \quad vr \leq \alpha\mu_j. \end{cases} \tag{13}$$

Equations (12) and (13) reveal that utility features determine the token price if and only if the opportunity cost vr of holding tokens exceed the token dividend yield $\alpha\mu_j$. Thus, in our framework, v and α determine the users' underlying motive to hold tokens. When v is relatively large compared to α, users hold tokens over an extended time period mainly for transaction purposes and, therefore, because of their utility features. By contrast, if v is low compared to α—for instance, when fiat money can be used as transaction medium on the platform and $v = 0$—tokens are only held for their cash flow rights and their price increases with α.

3.2 Model Solution before the Milestone

3.2.1 Incentive Compatibility

First, let us analyze developers' incentives to maximize the platform's transaction value through their effort choice a_t. Suppose developers exert effort, so that $a_t = 1$. With probability Λdt the milestone arrives over the next time interval and their payoff at τ equals:

$$\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}.$$

In contrast, if developers shirk and choose $a_t = 0$, then the user base after the milestone is N_L and their payoff at time τ equals:

$$\beta P_L + \frac{(1-\alpha)\mu_L N_L}{r}.$$

Hence, developers exert effort (i.e., $a_t = 1$) if:

$$IC(\alpha) := \underbrace{\Lambda\left(\beta v + \frac{(1-\alpha)\mu_H}{r}\right) N_H - \kappa}_{\text{Payoff under } a_t=1} - \underbrace{\Lambda\left(\beta v + \frac{(1-\alpha)\mu_L}{r}\right) N_L}_{\text{Payoff under } a_t=0} \geq 0. \tag{14}$$

Developers' incentives to exert effort are driven by the tokens they retain and their equity stake in the startup firm. Token-based incentives are captured by the retention level β. Equity incentives are captured by the fraction of the platform cash flows $1-\alpha$ accruing to the startup's owners.

3.2.2 Developers' Problem and Initial Token Issuance

We now analyze the platform development phase $[0, \tau)$. Throughout, we assume that financing needs are not prohibitively large and that full effort is optimal.

Assumption 1. *Exerting full effort $a_t = 1$ is efficient for all $t \leq \tau$ in that the project under full effort has a positive NPV. Formally, conditions (30), (31), (32) and (33) in Appendix A have to be met. In addition, developers optimally choose $a_t = 1$ for all $t \leq \tau$. Formally, condition (34) in Appendix A has to be met.*

When Assumption 1 is satisfied, we have $P_t = P_H$ after the milestone has been reached. The fair price of the token for risk-neutral users over $[0, \tau)$ is then given by:

$$P_t = P_0 = \frac{\Lambda P_H}{r + \Lambda}. \tag{15}$$

Notably, absent further constraints, developers and users value tokens equally before time τ as they both apply the same discount rate. However, because a higher retention level β relaxes condition (14), developers issue the minimal amount of tokens that is needed to cover the cost of platform development. We thus have:

$$(1-\beta_0)P_0 = I \iff \beta_0 = 1 - I/P_0. \tag{16}$$

Developers optimally also do not sell tokens over $(0, \tau)$ as there are simply no gains from trade.

Upon reaching the milestone, developers sell all retained tokens β at price P_H and further enjoy the perpetual dividend stream $(1-\alpha)N_H\mu_H$. Hence, developers' continuation value over $(0,\tau)$, conditional on full effort, is given by:

$$V(\alpha) = \frac{\Lambda(v\beta + (1-\alpha)\mu_H/r)N_H - \kappa}{r+\Lambda} \quad \text{with} \quad \beta = 1 - I/P_0, \tag{17}$$

and where we have used the market clearing condition: $P_H = vN_H$. We can rewrite the value function as:

$$V(\alpha) = \frac{\Lambda S(\alpha) - \kappa}{r+\Lambda} - I, \tag{18}$$

where

$$S = S(\alpha) = \left(v + \frac{(1-\alpha)\mu_H}{r}\right) N_H. \tag{19}$$

Equation (18) is simply the net present value of the project to developers, which is given by the value of the platform net of the investment cost. In this equation, $S(\alpha)$ is the sum of the token market capitalization, i.e., the value of all tokens in circulation, and the value of the startup equity after τ. Therefore, $S(\alpha)$ captures the monetary *platform value* after time τ, i.e., the overall surplus in dollar terms. In equation (19), vN_H is the dollar value of transactions conducted over $[t, t+vdt)$ while $(1-\alpha)\mu_H N_H$ is the dividend flow.

At time zero, developers design the token and choose the optimal level of dividend rights α to maximize the value they extract from the platform. That is, developers solve

$$\max_{\alpha\in[0,1]} V(\alpha) \quad \text{s.t.} \quad (14) \quad \text{and} \quad (4). \tag{20}$$

Using equation (18), we thus have that developers maximize $S(\alpha)$ subject to the incentive constraint (14) and the financing constraint (4). We conclude the section by establishing the existence of an equilibrium with positive adoption.[7]

Proposition 1. *There exists a unique Markov-Perfect Equilibrium with positive, maximal adoption after the milestone in that $N_t = N_H$, $\forall t \geq \tau$. In this equilibrium:*

1. *Developers' value is given by (18) and the token price is characterized by (13) and (15).*

2. *Developers sell tokens only at times 0 and τ and the retention level is given by (16) and $\beta_t = 0 \; \forall \; t \geq \tau$. The optimal α is characterized by (9).*

[7]Note that there are other degenerate equilibria in which no user adopts the platform and the platform and tokens are worthlesss. Throughout the paper, we do not direct our attention to these degenerate, less interesting equilibria.

3. *A token with both utility and security features is the optimal security among all securities that satisfy developers' and token holders' limited liability.*

4. *Issuing any other security, such as equity, next to tokens is never strictly optimal and is strictly sub-optimal if and only if the cost of platform development κ, platform financing needs I, or the expected time to platform development $1/\Lambda$ are sufficiently large.*

It is important to emphasize that a token with utility features characterized by (1) and security features characterized by (9) is in fact the optimal security that developers can issue to finance platform development. In particular, we demonstrate that it is optimal to bundle transaction benefits and dividends rights in (i.e., attach utility and security features to) *one* security rather than offering *two* securities that deliver dividends and transaction benefits separately. As noted above, the mechanism underlying this finding is that granting dividend rights to token holders spurs adoption, thereby increasing platform value.

Appendix C analyzes the special case in which developers issue startup equity next to tokens in greater detail. We demonstrate in this appendix that token-based financing dominates equity-based financing in the presence of moral hazard and financing frictions. The intuition, formalized in the following sections, is that equity issuance implies a greater dilution of developers' stake in the startup firm than token issuance, thereby exacerbating the moral hazard problem. We also demonstrate that any other security that developers might want to issue in our model is equity like, leading to claim 4 of Proposition 1.

4 Analysis

4.1 The Frictionless Benchmark

We start by studying the model without moral hazard. In this frictionless benchmark, the incentive constraint (14) becomes irrelevant, and developers choose α to maximize the platform value $S(\alpha)$. This holds true even if $I > 0$

The following Proposition demonstrates that absent agency conflicts and transaction costs (i.e., for low ϕ) full dividend rights $\alpha = 1$ are optimal. It also shows that an increase in transaction costs generally reduces the optimal amount of security features.

Proposition 2. *Assume that $vr \geq \mu_H$. Absent moral hazard, it follows that $\bar{\alpha} = \arg\max_\alpha S(\alpha)$ satisfies:*

$$\bar{\alpha} = \begin{cases} 1 & \text{if } vr \geq \frac{(1-\xi)(\phi-\mu_H)}{\xi} \\ 0 & \text{if } vr \leq \frac{(1-\xi)\phi-\mu_H}{\xi} \\ \frac{vr}{\mu_H} + \frac{1}{\xi} - \frac{\phi(1-\xi)}{\xi\mu_H} & \text{otherwise.} \end{cases}$$

Because developers and users discount at the same rate r, they also value dividends—ceteris paribus—the same. However, dividends paid to users rather than to developers increase the returns to holding tokens and spur transaction volume and adoption. This in turn boosts cash flows and, as a result, dividends to token holders and adoption. That is, security features induce *endogenous* network effects via the cash flow channel. Therefore, absent frictions it is optimal to allocate full cash flow rights to users when the cost of transacting on the platform is small and does not represent an impediment to platform development.

To conclude the section, we make the following assumption:

Assumption 2. *We assume the following parameter conditions:*

1. *Transaction costs are sufficiently low in that $vr + \frac{(1-\xi)(\mu_H-\phi)}{\xi} \geq 0$.*

2. *The token is always priced according to its utility features in that $vr \geq \mu_H$.*

In the analysis that follows, we assume that Assumption 2 holds. Thus, we focus on environments in which transaction costs are low and the token is priced according to its utility features implying that $\bar{\alpha} = 1$ absent moral hazard. As we show below, all frictions drive the level of security features below $\bar{\alpha}$, so that this choice can be viewed as a normalization.

4.2 Moral Hazard and Financing Needs

As shown by (20), developers maximize $S(\alpha)$ subject to the incentive constraint (14) and the financing constraint (4). Since $\bar{\alpha} = 1$ and (4) is optimally tight as in (16), developers choose the maximal value α that satisfies the incentive constraint (14). Therefore, the optimal level of security features α in the tokens issued by the startup firm is given by:

$$\max_{\alpha \in [0,1]} \alpha \quad \text{s.t.} \quad IC(\alpha) \geq 0.$$

We can now examine how the optimal level of security features α and the token retention level β depend on moral hazard and financing needs. In the absence of financing needs, i.e., when

$I = 0$, developers retain all tokens and are therefore able to capture all the monetary proceeds that the platform generates. As a result, even if $\kappa > 0$, there are no agency conflicts in that developers maximize $S(\alpha)$ and choose $\alpha = \bar{\alpha} = 1$. Conversely, financing needs $I > 0$ lead to a lower token retention level $\beta < 1$ and give rise to agency conflicts between developers (insiders) and users (outsiders). These agency conflicts affect the optimal design of tokens and therefore platform value, which in turn determines the severity of the financing frictions. In the following, we analyze how moral hazard and financing needs jointly shape the design of tokens and the provision of incentives.

When $\alpha < 1$ and $\beta > 0$, developers have both equity-based incentives and token-based incentives. Equity-based incentives primarily relate to platform cash flows. Token-based incentives primarily relate to platform adoption. Because a higher platform adoption also leads to higher cash flows, equity-based incentives de facto generate payoff sensitivity to both platform adoption and cash flows. More formally, observe that for any given α, the value of developers' equity before time τ satisfies

$$E(A) = \frac{\Lambda}{r + \Lambda} \frac{(1 - \alpha)N(A)\mu(A)}{r}$$

where the second term on the right hand side of this equation represents the value of equity at time τ. This implies that the incentives (i.e., the sensitivity with respect to productivity A) generated by a dollar of equity ownership are equal to

$$\frac{dE/dA}{E} = \underbrace{\frac{d\mu/dA}{\mu}}_{\substack{\text{Cash flow} \\ \text{sensitivity}}} + \underbrace{\frac{dN/dA}{N}}_{\substack{\text{Sensitivity} \\ \text{to platform} \\ \text{adoption}}}, \tag{21}$$

whereas the incentives from a dollar token ownership are equal to

$$\frac{dP/dA}{P} = \frac{dN/dA}{N}. \tag{22}$$

Equations (21) and (22) show that, as long as cash flows increase with platform productivity, equity incentives are stronger than token-based incentives. Because of their greater strength, equity incentives are particularly important in firms characterized by severe moral hazard, i.e., when $A_H - A_L$, I, $1/\Lambda$, or κ are sufficiently large. However, equity incentives reduce token security features and therefore platform adoption and value. Consequently, the provision of equity incentives requires developers to sell more tokens at inception, thereby reducing the token retention level β and exacerbating moral hazard. In sum, financing needs and moral hazard reinforce each other and determine the optimal composition of incentives to developers, as captured by $1-\alpha$ and β.

Incentives optimally become more equity-based and less token-based if the cost of effort (i.e., κ), the expected time to platform development (i.e., $1/\Lambda$), or financing needs (i.e., I) increase. That is, financing and agency frictions or a long platform development phase lead to an under-provision of token security features and, remarkably, also to a low level of token retention. This result is driven by the greater power of equity-based incentives, which implies that the startup firm sells more tokens with lower dividend rights when frictions are larger.

Figure 2 illustrates these findings by plotting the optimal level of token security features α and developers' retention level β as functions of financing needs, the expected time to platform development, and agency frictions. Input parameter values for this figure are described in Appendix A. They follow from prior contributions in the literature and imply an optimal retention level of $\beta = 39\%$ in our base case environment, in line with the average retention level reported in Fahlenbrach and Frattaroli (2019). The right panels of Figure 2 demonstrate the effects of agency and financing frictions on platform adoption when the token is optimally designed; as discussed above a decrease in security features leads to a decrease in platform adoption.

The following proposition gathers our analytical results.

Proposition 3. *The optimal level of token security features satisfies $\alpha = \bar{\alpha}$ if either:*

1. *κ or $1/\Lambda$ sufficiently low;*
2. *I sufficiently low;*
3. *or $\mu_H - \mu_L$ sufficiently low; this is the case if $A_H - A_L$ is sufficiently low.*

In addition, $\frac{\partial IC(\alpha)}{\partial \xi} > 0$ for any $\alpha \in [0,1]$ and the optimal token retention level satisfies

$$\frac{d\beta}{dI} < 0, \frac{d\beta}{d\Lambda} > 0, \frac{d\beta}{d\xi} > 0 \quad \textit{and} \quad \frac{d\beta}{d\kappa} \leq 0,$$

where the latter inequality is strict if and only if the incentive condition (14) is tight.

Interestingly, stronger network effects ξ relax the incentive condition (14). The intuition is that strong network effects make developers' revenues more contingent on platform adoption, thereby aligning users' and developers' incentives. In addition, stronger network effects make it more valuable to grant dividend rights to token holders. The underlying reason is that security features lead to higher cash flows to token holders and boost adoption, which triggers even higher cash flows

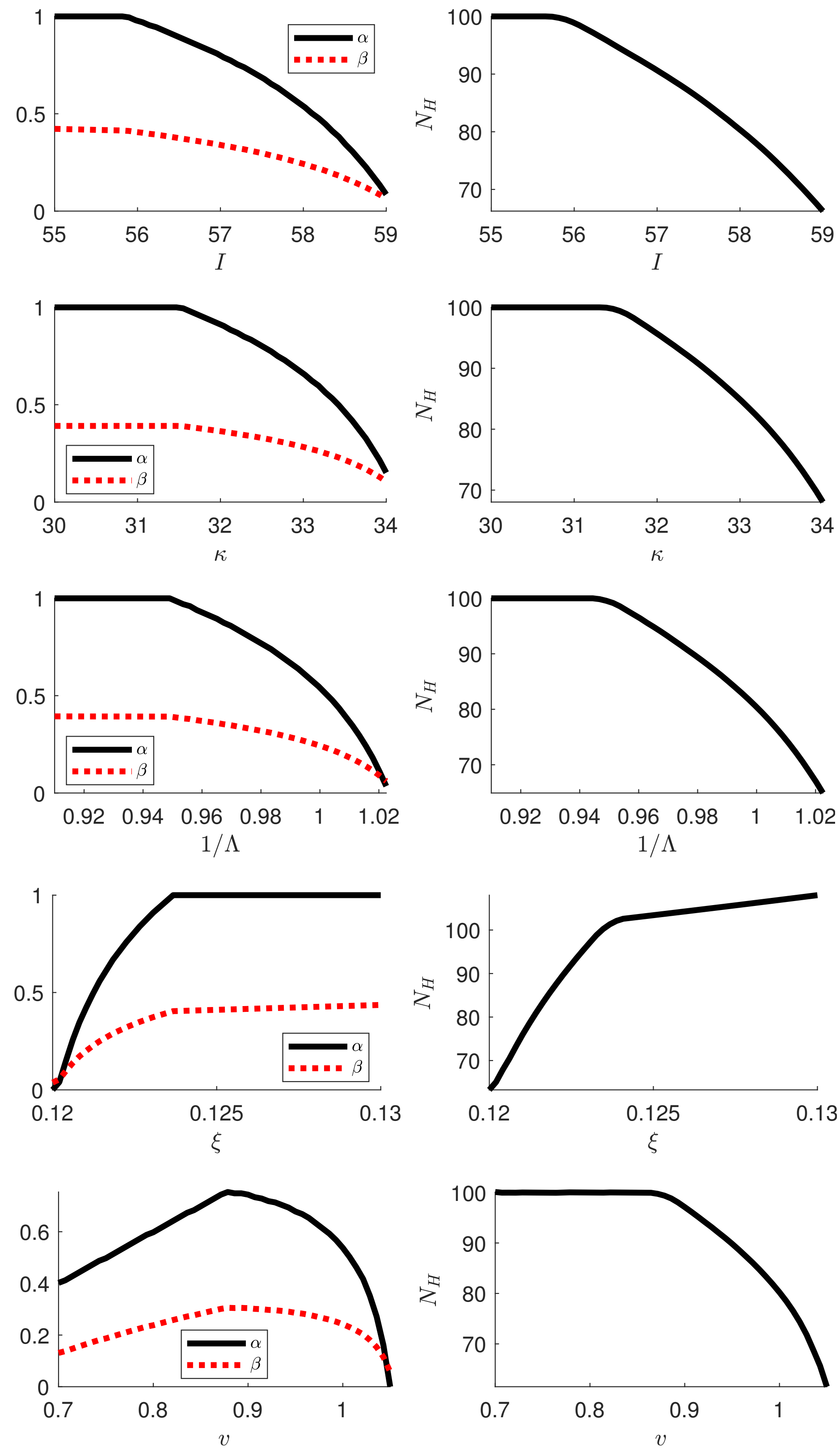

Figure 2: The effects of financing needs I, moral hazard κ, expected time to platform development $1/\Lambda$, network effects ξ, and token velocity v on token design and platform adoption.

and adoption. These endogenous network effects arising from the cash flow channel are amplified by the exogenous network effects ξ. As a result, stronger network effects imply more token-based incentives, i.e., a higher retention level β, and less equity incentives $1-\alpha$ to developers. These effects are illustrated in Figure 2.

4.3 Token Velocity

Token price and platform adoption are closely related to the *token velocity*, which is defined as the ratio of the platform's real transaction value over the token market capitalization. In our model, it is given by:

$$velocity := \frac{N_t}{P_t} = \min\left\{\frac{1}{v}, \frac{r}{\alpha\mu(A_t)}\right\}. \tag{23}$$

This equation shows that if the token is priced according to its utility features, token velocity equals the inverse of the holding period v. Remarkably, security features $\alpha > 0$ bound the token velocity from above and so can be useful to address problems associated with high token velocity.[8] In the following, we study how token velocity affects developers' incentives, the design of tokens, and platform adoption.

To start with, note that an increase in v raises the cost of transacting for users. Therefore, a lower velocity hampers adoption in that $\frac{\partial N_H}{\partial v} < 0$, but may boost the token price due to the market clearing condition $P_H = vN_H$. As a result, a lower token velocity not only reduces the power of equity incentives but also may relax financing constraints and increase token incentives. Conversely, a high token velocity implies not only high-powered equity incentives but it may also tighten financing constraints and lower token incentives. Overall, agency conflicts and financing frictions are particularly severe if token velocity is excessively high or low. When this is the case, the token security features α and the token retention level β are low, as illustrated by Figure 2.

The following corollary summarizes our main analytical results on the effects of token velocity:

Corollary 1. *The following holds:*

1. *If $(1-\xi)\phi > \mu_H$, excessive token velocity, i.e. $v \leq \mu_H\alpha$, reduces platform value.*

2. *If v and I are sufficiently large, then $\frac{\partial IC(\alpha)}{\partial v} < 0$ for all $\alpha \in [0,1]$ and $\frac{d\beta}{dv} < 0$*

3. *If $v \geq \frac{\mu_H\alpha}{r}$ is sufficiently low, then $\frac{\partial IC(\alpha)}{\partial v} > 0$ for all $\alpha \in [0,1]$ and $\frac{d\beta}{dv} > 0$*

[8] The token velocity problem is widely discussed among crypto-practicioners (see e.g. https://www.coindesk.com/blockchain-token-velocity-problem).

5 Alternative Ways of Financing

We have shown so far that the optimal token generally exhibits both utility and security features in the presence of agency conflicts and financing frictions. This section explicitly examines when omitting either utility or security features is optimal.

5.1 ICO vs. STO: When to Include Token Security Features?

In our framework, the token does not exhibit security features when $\alpha = 0$. In this case, the token derives its value only from its transaction benefits. Such tokens are generally referred to as utility tokens and issued in a lightly regulated way by means of an initial coin offering (see Howell et al. (2019), Fahlenbrach and Frattaroli (2019)). We turn now to analyzing when and why an initial coin offering (ICO) may be preferred to a security token offering (STO).

The following corollary establishes that whether an ICO is preferred to a security token offering depends on the nature of the startup's product.

Corollary 2. *An initial coin offering (i.e., $\alpha = 0$) is optimal if*

$$\mu_H \leq (1 - \xi)\phi - \xi v r.$$

A security token offering (i.e., $\alpha > 0$) is optimal if

1. $\mu_H > (1 - \xi)\phi - \xi v r$,
2. κ, $1/\Lambda$, I, *or* $\mu_H - \mu_L$ *is sufficiently small.*

The comparison between an ICO and STO can be conducted for a fixed platform value, since the statements in Corollary 2 do not explicitly involve A_H. The inequality conditions in Corollary 2 imply that when the platform is expected to generate low (or even negative) cash flows (i.e., for low μ_H), the ICO financing model is optimal. In this case, the platform essentially derives its value from facilitating transactions among users. By contrast, the platform's ability to generate cash flows adds value to security token offerings even though the issuance of a security token dilutes developers' cash-flow rights. The economic mechanism behind this result is that granting dividend rights to users spurs platform adoption, which is particularly valuable for large μ_H. Corollary 2 also implies that stronger network effects (i.e., high ξ) favor STOs. This is because dividend rights embedded in security tokens magnify network effects and spur platform adoption even more.

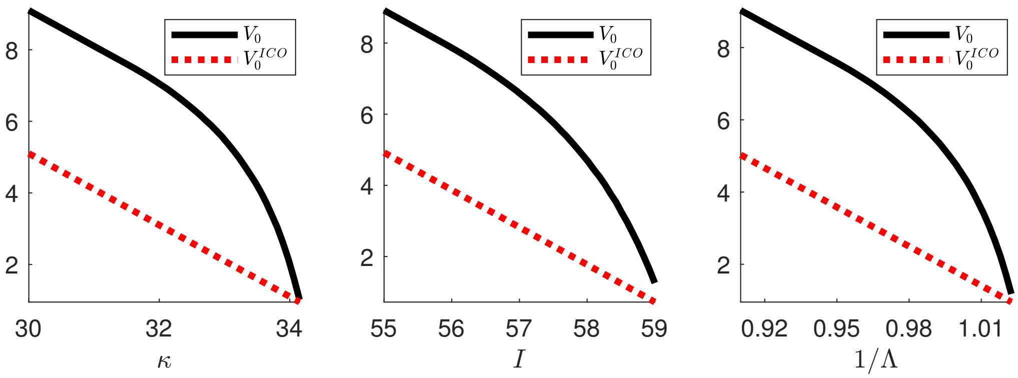

Figure 3: ICO versus STO. V_0 and V_0^{ICO} represent the developers value under the optimal security token ($\alpha > 0$) and utility token ($\alpha = 0$), respectively.

Finally, financing and agency frictions make security tokens and STOs less attractive. This is the case because an increase in frictions renders equity incentives more valuable, thereby reducing the value of security tokens relative to utility tokens. Likewise, platform projects with long expected times to development are subject to more severe moral hazard and, therefore, are more suitable for ICO financing. Interestingly, several empirical studies (see e.g. Howell et al. (2019) or Fahlenbrach and Frattaroli (2019)) report that many ICO financed projects have not yet managed to deliver their promised product. While this fact is often interpreted as evidence for the failure of the ICO financing model, our analysis suggests the opposite in that projects with longer expected times to completion especially benefit from ICO financing.

Figure 3 illustrates these relations for various levels of the cost of effort κ, the expected time to platform development $1/\Lambda$, and financing needs I. Our baseline parameter values are such that STOs dominate ICOs but the overall pattern is that under severe financing and agency frictions, it becomes optimal to issue a pure utility token via an ICO to avoid diluting developers' equity stake.

5.2 Fiat Money vs. Tokens: When to Include Token Utility Features?

When tokens do not have utility features, fiat money is used as platform transaction medium. When this is the case, we have $v = 0$ and the adoption level and token price are given by

$$N_H = \left(\frac{A_H}{\phi}\right)^{\frac{1}{1-\xi}} \quad \text{and} \quad P_H = \frac{\alpha \mu_H N_H}{r}.$$

Allowing fiat money as transaction medium removes the token holding period vdt and therefore reduces users' effective transaction costs. As a result, fiat money as transaction medium potentially spurs adoption and this effect is stronger when platform network effects are stronger.

Without token utility features, the token price is the present value of the dividend stream to token holders and the token essentially represents an equity claim. This implies that token and equity incentives are equivalent so that the choice of α becomes irrelevant. Notably, the overall surplus satisfies:

$$S(\alpha) = P_H + \frac{(1-\alpha)\mu_H N_H}{r} = \frac{\mu_H N_H}{r},$$

which is just the expected dividend stream of the platform and is independent of the choice of α.

In general, platform developers can choose between attaching utility features to tokens, i.e., setting $v^* = v$, or omitting them, i.e., setting $v^* = 0$, where the parameter v is given and exogenously fixed, e.g., due to technological constraints. As a result, developers' optimization problem reads

$$V_0 = \max_{\alpha, v^* \in \{0,v\}, \{\beta_t\}, \{a_t\}} \mathbb{E}\left[\int_0^\infty e^{-rt}(-P_t\, d\beta_t + (1-\alpha+\alpha\beta_t)dD_t - \kappa a_t dt)\right] - I. \tag{24}$$

Corollary 3 derives conditions under which token utility features are optimal.

Corollary 3. *Under Assumption 2 (which guarantees that $vr \geq \mu_H$), a fiat-based platform is optimal if*

$$\frac{\mu_H}{vr} \geq \left(\frac{\phi}{\max\{vr - \mu_H, 0\} + \phi}\right)^{\frac{1}{1-\xi}}, \tag{25}$$

and always leads to a higher level of adoption. Condition (25) is satisfied if v is sufficiently large or if $\mu_H \geq \phi(1-\xi)$. A token-based platform is optimal if

1. *Condition (25) is not satisfied,*

2. *κ, $1/\Lambda$, I, or $\mu_H - \mu_L$ is sufficiently small.*

Corollary 3 shows that tokens with utility features are optimal if network effects are weak or platform cash flows are low. In these instances, the issuance of a token that serves as a platform transaction medium allows developers to raise more funds, which mitigates financing frictions (see Corollary 1) and contributes to platform success. Conversely, a token without utility features is optimal only if the platform cash flows are high. In this case, the startup in effect uses fiat money as a transaction medium and is essentially financed with equity. If, in addition, network effects are strong, reducing transaction costs by allowing users to transact by means of fiat money boosts adoption. As expected, using fiat money as a platform transaction medium becomes also optimal if the cost of using a token for transactions v is large.

Issuing tokens with utility features rather than fiat money for platform transactions can be optimal if financing and agency frictions are not too severe. To understand this finding, note that a fiat-based platform implies that developers' value fully stems from their equity ownership in the startup firm. Hence, developers' incentives are equity-based and therefore stronger, which is particularly valuable if financing needs and moral hazard are severe. In line with this reasoning, tokens without utility features are preferred for large values of κ, I, $\mu_H - \mu_L$, and $1/\Lambda$.

The following corollary presents an overview of the findings in Sections 5.1 and 5.2.[9]

Corollary 4. *Suppose that* $vr > (1-\xi)\phi$. *Then, there exists unique* $\overline{\mu} \in (\phi - vr\xi/(1-\xi), \phi(1-\xi))$ *such that an ICO (i.e.,* $\alpha = 0, v^* = v$*) is optimal if* $\mu_H \in [0, (1-\xi)\phi - vr\xi)$*, an STO (i.e.,* $\alpha > 0, v^* = v$*) is optimal if* $\mu_H \in [(1-\xi)\phi - vr\xi, \overline{\mu})$*, and a token without utility features (i.e.,* $v^* = 0$*) is optimal if* $\mu_H \in [\overline{\mu}, \infty)$*.*

Corollary 4 establishes that tokens with utility features are important to finance digital platforms that create value by facilitating transactions among users but exhibit limited potential to produce cash flows. Crucially, such projects may not be able to raise funds by means of conventional securities. As a result, the issuance of (transaction) tokens facilitates the financing of valuable projects that otherwise could not receive financing. By contrast, if its cash flow rate is sufficiently large, the startup optimally issues a token without utility features, that resembles traditional equity. Hence, projects with high cash flow potential μ_H are de-facto equity financed. More broadly, our model implies that startups with relatively unproven business models, which are unlikely to produce high cash flows, rely on token-based financing, which is consistent with the findings of Fahlenbrach and Frattaroli (2019) and Howell et al. (2019).

6 Endogenous Transaction Fees

Suppose now that developers can dynamically charge a fee $f > 0$ to users for transacting on the platform. This fee increases users' direct cost of transacting to $f + \phi$ and platform cash flows to

$$dD_t = (\mu(A_t) + f)N_t dt.$$

[9] Corollary 4 can be restated in terms of the network effects parameter ξ in that an ICO is optimal for low values of ξ, an STO is optimal for moderate values of ξ, and a fiat based platform is optimal for large values of ξ.

Using the same steps as above, it is immediate to show that the level of platform adoption becomes

$$N_H = \left(\frac{A_H}{\max\{0, vr - \alpha(\mu_H + f)\} + \phi + f} \right)^{\frac{1}{1-\xi}}, \tag{26}$$

when the platform charges transaction fees. In the following, we consider that developers cannot commit at time zero to future transaction fees. Appendix F analyzes the case of full commitment.

Without commitment, the optimal dynamic fee f maximizes at each point in time the dividends accruing to developers:

$$(1 - \alpha + \beta\alpha)(\mu_H + f)N_H$$

and therefore maximizes platform cash flows $(\mu_H + f)N_H$.[10] This leads to the following result.

Proposition 4. *The optimal dynamic fee for platform developers satisfies*

$$f^* = \min\left\{ \frac{(1-\xi)(vr+\phi) - \mu_H}{\xi(1-\alpha)} + \alpha\mu_H, \frac{vr}{\alpha} - \mu_H \right\}.$$

The fee increases in α for $\alpha \leq \alpha_1$ and decreases in α for $\alpha \geq \alpha_1$, where $\alpha_1 \in (0,1)$ solves

$$\frac{(1-\xi)(vr+\phi) - \mu_H}{\xi(1-\alpha)} + \alpha\mu_H = \frac{vr}{\alpha} - \mu_H$$

if $(1-\xi)(vr+\phi) > \mu_H$ and equals one otherwise. The resulting adoption level satisfies

$$N_H^f = \begin{cases} \left(\frac{A_H \xi}{vr+\phi-\mu_H}\right)^{\frac{1}{1-\xi}} & \text{if } \alpha \leq \alpha_1 \\ \left(\frac{A_H}{vr/\alpha+\phi-\mu_H}\right)^{\frac{1}{1-\xi}} & \text{otherwise.} \end{cases}$$

Proposition 4 shows that the optimal dynamic fee depends on whether the token utility or security features pin down the token price (i.e., whether $\alpha \leq \alpha_1$ or $\alpha > \alpha_1$, respectively). Moreover, the optimal fee follows a hump-shaped pattern in α. The optimal level of security features with endogenous transaction fees is then characterized in the following corollary.

Corollary 5. *Security features with $\alpha \in (\alpha_1, 1)$ are never optimal with endogenous transaction fees. Tokens with $\alpha \leq \alpha_1$ yield the same profit as tokens with $\alpha = 0$ and are optimal if and only if*

$$(1-\xi)(\phi - \mu_H) + vr \geq vr\xi^{\frac{1-\xi}{\xi}} \tag{27}$$

[10] We assume that even if $\alpha = 1, \beta = 0$ developers set fees in order to maximize $(\mu_H + f)N_H$.

and therefore always optimal if $\phi \geq \mu_H$. Tokens with $\alpha = 1$ are optimal if and only if Condition (27) *is not satisfied. Platform adoption is higher for $\alpha = 1$ than for $\alpha \leq \alpha_1$.*

If the token is priced according to its utility features, then the optimal transaction fee satisfies $f^* < \frac{vr}{\alpha} - \mu_H$. In this case, users effectively incur the transaction fee $f^*(1-\alpha)$. The reason is that a fraction α of the transaction fees flows back to users in the form of dividends. Higher α in turn implies higher dividends, which allows developers to charge higher fees without endangering adoption. In this context, the issuance of a utility token (i.e., $\alpha = 0$) can be viewed as a commitment device not to charge high fees in the future.

If the token is priced according to its security features, then $f^* = \frac{vr}{\alpha} - \mu_H$ and developers charge lower transaction fees as token cash flow rights increase, in an attempt to limit purely return-driven investments and maximize adoption. Also note that, even if $\alpha = 1$, the proceeds from transaction fees do not fully flow back to users but partially accrue to (return-driven) token investors, who do not transact. In sum, both high and low token security features serve as commitment device for low future transaction fees and, thus, are particularly useful for platform building in the presence of commitment problems to future fees. As a result, either $\alpha = 1$ or $\alpha \leq \alpha_1$ is optimal.

Interestingly, the optimal transaction fee f can be negative. In this case, the startup firm *subsidizes* the user base in order to accelerate platform adoption. In practice, such subsidies are commonly employed by large technology firms. For instance, Alibaba implemented in 2019 a reward scheme providing subsidies to attract developers to its various platforms (Chod et al. (2019)). In addition, Uber is going to offer financial services, including loans to drivers at favorable rates.[11]

Corollary 6. *Subsidies $f < 0$ are optimal if*

$$\mu_H > \mathcal{S} := \frac{(1-\xi)(vr+\phi) + \xi(1-\alpha)}{1-\xi(1-\alpha)}.$$

As shown in Corollary 6, subsidies to the user base are more likely if the platform is financed with utility tokens (i.e., for $\alpha = 0$) or if network effects are strong. In addition, subsidies are only optimal if the platform generates enough revenues μ_H to finance these subsidies. We also show in the Appendix that subsidies are more likely if the blockchain technology facilitates commitment.

[11] https://www.cnbc.com/2019/10/28/uber-announces-deeper-push-into-financial-services-with-uber-money.html.

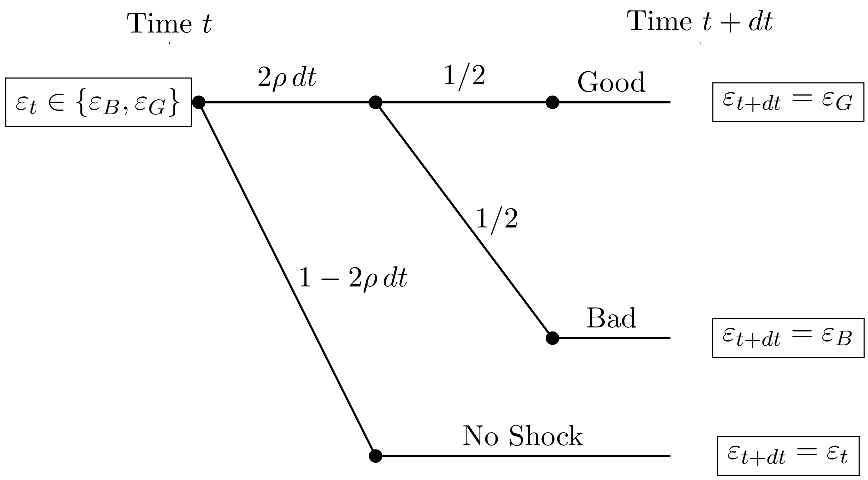

Figure 4: Productivity shocks over $[t, t + dt)$. The branches of the tree contain the probabilities of the respective random event over $[t, t + dt)$.

7 Productivity Shocks and Token Price Volatility

We now allow for uncertainty after the milestone is reached by introducing persistent productivity shocks which are not affected by developers' actions. Importantly, the introduction of productivity shocks after time τ does *not* affect qualitatively developers' decisions before time τ, in that the results derived above continue to hold (see Appendix D). Our focus in this section is therefore not on developers' problem but on the asset pricing implications of token utility and security features.

We introduce productivity shocks in our model by assuming that for $t \geq \tau$ and $\bar{A} \in \{A_L, A_H\}$, platform productivity is given by

$$A_t = \bar{A} + \varepsilon_t, \quad \text{with } \varepsilon_t \in \{\varepsilon_B, \varepsilon_G\} \text{ and } \bar{A} + \varepsilon_B \geq 0 \text{ and } \varepsilon_G \geq \varepsilon_B.$$

Productivity shocks are as follows. If $\varepsilon = \varepsilon_G$, the platform is subject to a negative productivity shocks $dA = \varepsilon_B - \varepsilon_G$ over dt with probability ρdt. Likewise, if $\varepsilon = \varepsilon_B$, the platform experiences a positive shock $dA = \varepsilon_G - \varepsilon_B$ with probability ρdt. Consequently, the volatility of the productivity shocks, i.e., the fundamental volatility, is given by $\varepsilon_G - \varepsilon_B$. We emphasize that productivity shocks—unlike $\bar{A}$—are purely random and not affected by developers' actions.

In general, there are many benefits to having a stable transaction medium (Doepke and Schneider (2017)). For instance, price fluctuations expose transacting users to risks during the transaction settlement period and lead to a drop in users' transaction activities. Excessive price volatility is thus likely to hamper platform adoption. This implies that platform projects should aim for a relatively stable token price and so should try to limit price fluctuations and volatility.

7.1 Solution

We characterize the equilibrium token pricing after time τ for a given $A_t = \bar{A}$. Formally, we have to derive the adoption levels N_G and N_B and the token prices P_G and P_B. A measure of price volatility is then given by $\sigma := P_G - P_B$. Assume that utility features price the token so that $P_j = vN_j$. Then the token prices P_G and P_B solve:

$$P_G = P_G(\alpha) = v\left(\frac{\bar{A}+\varepsilon_G}{vr - \alpha\mu(\bar{A}+\varepsilon_G) + \phi - \rho(P_B/P_G - 1)}\right)^{\frac{1}{1-\xi}}, \tag{28}$$

$$P_B = P_B(\alpha) = v\left(\frac{\bar{A}+\varepsilon_B}{vr - \alpha\mu(\bar{A}+\varepsilon_B) + \phi - \rho(P_G/P_B - 1)}\right)^{\frac{1}{1-\xi}}. \tag{29}$$

The following Proposition summarizes these findings.

Proposition 5. *Suppose that $\mathbb{E}(dP_t + \alpha dD_t) < rP_t dt \quad \forall t \geq \tau$ so that the token is priced according to its utility features. Given $\bar{A}$, the unique equilibrium with maximal adoption satisfies* (28)-(29).

7.2 Token Price Volatility: The Role of Utility and Security Features

In general, the token prices P_G and P_B are not available in closed form. A notable simplification arises in the limit case $\max_A |\mu'(A)| \to 0$ and $\xi \to 0$. While $\xi \to 0$ precludes network effects arising from specification (1), our model still features endogenous network effects in that a higher adoption level N_t leads to higher cash flows and dividends, which in turn increases N_t. Likewise, the slope $\mu'(A)$—unlike the level $\mu(A)$—is not essential for the asset pricing implications. Thus, the findings presented in this section are likely to hold for more general specifications.

First, consider that token utility features pin down the token price in that the token derives its price from the level of adoption and $N_t = vP_t$. In this case, we have that

$$\sigma \simeq \frac{v(\varepsilon_G - \varepsilon_B)}{vr - \alpha\mu + \phi + 2\rho} = \sigma_U.$$

Naturally, volatility increases with fundamental volatility $\varepsilon_G - \varepsilon_B$. More interestingly, dividend rights α amplify rather than curb the volatility. The reason is that higher dividend rights imply endogenous network effects. These network effects increase the sensitivity of platform adoption to productivity shocks. This boosts the token price volatility because the token derives its value from the level of platform adoption. Notably, due to the endogenous network effects, volatility σ is increasing and convex in security features α. In sum, while network effects induced by token security features may spur adoption, they also amplify price volatility.

Second, let us consider the token is priced according to its security features in both states G and B. In this case, we have that

$$\sigma \simeq \frac{\alpha\mu(\varepsilon_G - \varepsilon_B)}{r+\rho} =: \sigma_S.$$

That is, when the token is priced according to its security features, σ is linear in α and therefore less sensitive to the provision of security features. The reason for this decreased sensitivity is that dividends do not generate network effects if the token is priced according to its security features.[12]

The above results imply that the combination of token utility and security features implies high-powered network effects and causes a particularly high price volatility. In addition, we can analyze how the token velocity interacts with the token price volatility when the token is priced according to its utility features. In particular, we have that

$$sign\left(\frac{\partial\sigma_U}{\partial v}\right) = \phi + 2\rho - \alpha\mu.$$

That is, a longer token holding period, i.e., a higher token velocity, may or may not stabilize token prices. In line with Assumption 1, we consider small values of ϕ and also small ρ. In this case, our model implies that token velocity amplifies the token price volatility.

Corollary 7. *In the limit case of* $\max_A |\mu'(A)| \to 0$ *and* $\xi \to 0$*, the following holds:*

1. *If the token is priced according to its utility features in both states G and B, then σ is increasing and convex in α. In addition:*

$$sign\left(\frac{\partial\sigma}{\partial v}\right) = \phi + 2\rho - \alpha\mu.$$

2. *If the token is priced according to its security features in both states G and B, then σ is linearly increasing in α.*

[12] We do not explicitly study the last remaining scenario, in which the token is priced as security in the state B yet according to its utility features in state G.

8 Conclusion

We study a model in which a start-up firm run by developers launches a digital platform. To finance platform development, developers issue tokens that serve as the transaction medium on the platform and thus possess utility features. Tokens may additionally possess cash flow rights and, thus, security features. In the model, platform development is subject to financing needs and moral hazard. This unified model allows us to identify the costs and benefits of various token designs used in practice to finance startup firms.

We show that dividend rights granted to token holders spur platform adoption but dilute developers' equity stake and therefore undermine their incentives. As a result, an increase in financing needs or in agency frictions leads to a decrease in token security features. The model also derives conditions under which different types of financing modes are optimal. Specifically, a security token offering or an initial coin offering always dominates traditional equity financing due to network effects. By contrast, whether a security token offering is preferred to an initial coin offering crucially depends on platform and startup characteristics, notably the ability to generate cash flows in addition to facilitating transactions among users. In platforms that charge transaction fees to users, the ICO financing model can serve as a commitment device by developers to maintain low fees. We also show that platforms optimally use either fiat money or tokens as a transaction medium depending on platform characteristics. Notably, fiat money is only optimal for platforms characterized by high earnings, strong network effects, and high agency frictions. Lastly, we examine the asset pricing implications of security features embedded in tokens.

Appendix

A Discussion of Parametric Assumptions

Optimality of Effort & Financing Needs. Unless otherwise mentioned, we assume that the following parameter conditions hold:

1. We assume that $\bar{\alpha} = 1$ in that ϕ is not too large:
$$vr + \frac{(1-\xi)(\mu_H - \phi)}{\xi} \geq 0 \tag{30}$$
The derivation of this condition is in Proposition 2.

2. We assume that full effort, conditional on $\alpha = 1$, is efficient in that:
$$\Lambda(P_H(1) - P_L(1)) > \kappa \tag{31}$$
This is essentially the IC condition (14) evaluated at $\alpha = 1$.

3. We assume the project has positive NPV, given optimal $\alpha = 1$:
$$\frac{\Lambda P_H(1)}{r + \Lambda} > I. \tag{32}$$

4. We assume that utility features pin down the token price, for any $\alpha \in [0,1]$:
$$\mu_H \leq vr. \tag{33}$$
The consequences of this condition on token pricing become apparent in the discussion of the equilibrium.

5. We assume that developers always derive higher payoff from exerting effort $a_t = 1$ in that:
$$\max_{\alpha,\beta} \left(\Lambda \left(\beta v + \frac{(1-\alpha)\mu_H}{r} \right) N_H - \Lambda \left(\beta v + \frac{(1-\alpha)\mu_L}{r} \right) N_L - \kappa \right) > 0 \text{ s.t. } (14), (4). \tag{34}$$

Parameters for the numerical analysis. As in Cong et al. (2019b), we set the discount rate to $r = 0.05$ and velocity $v = 1$. Likewise, we follow Cong et al. (2019b) and set the network effects parameter to $\chi = 0.125$. The CRRA parameter is set to $\eta = 0.375$ implying that $\xi = 0.5$. Interpreting one unit of time as one year, we set $\Lambda = 1$ implying that developers retain tokens for about one year. This is consistent with the findings of Fahlenbrach and Frattaroli (2019) who report that the weighted-average lock up period for tokens is about one year. We normalize $A_H = 1$. In fact, the absolute value of A_H is not particularly important; instead its relationship with A_L matters. The value A_L is set to $A_L = 0.55$.

The function $\mu(A)$ takes the general power form $\mu(A) = \bar{\mu}A^\omega$ with $\omega \in [0, \infty]$. We pick $\bar{\mu} = 0.025$ which ensures that $\mu(A_H) < vr$ as stipulated by Assumption 1. We set $\omega = 10$ in order to emphasize the importance of the nature of platform applications for token offerings, as documented for ICOs by Howell et al. (2019). We pick $\phi = 0.075$ in order to normalize N_H in the frictionless case to $N_H = 100$. This is convenient because any value N can be interpreted in percentage terms of the adoption level N_H in the frictionless benchmark. Notably, $\phi = 0.075$ also satisfies Assumption 1.

We choose I in order to match sample average of token retention levels for ICOs. Specifically, we set $I = 58$ which implies in the frictionless benchmark the retention level $\beta = 39\%$, the average token retention level reported for ICOs by Fahlenbrach and Frattaroli (2019). The effort cost κ is varied and chosen so as to generate the desired tensions. We set $\kappa = 33.33$ which is 33.33% of the token price in the frictionless benchmark. This way we capture the high degree of agency problems and agency costs prevailing in this market (Howell et al. (2019), Fahlenbrach and Frattaroli (2019)).

When we vary κ and I, we make sure that Assumption 1 is satisfied. This implies $\kappa < 34.15$ and $I < 59.5$. A similar constraint applies to ξ and v. When we vary v, we employ a lower level $\phi = 0.0735$ in order to satisfy Assumption 1 across the whole range of values of v considered. We emphasize that our results are robust across various choices of parameter values.

B Omitted Proofs

B.1 Additional Result

We state an auxiliary Lemma:

Lemma 1. *It holds that*

$$\arg\max_{\alpha} S(\alpha) = \arg\max_{\alpha} \left(\beta v + \frac{(1-\alpha)\mu_H}{r}\right) N_H - \frac{\kappa}{\Lambda} \quad \textit{with } \beta(\alpha) = 1 - \frac{(\Lambda + r)Iv}{\Lambda N_H}.$$

Proof. Define $\varepsilon := 1/(1-\xi)$. Note that:

$$\alpha^* = \arg\max_{\alpha \geq 0} \left(\beta v + \frac{(1-\alpha)\mu_H}{r}\right) N_H - \frac{\kappa}{\Lambda} \quad \text{with } \beta(\alpha) = 1 - \frac{(\Lambda + r)Iv}{\Lambda N_H}.$$

Note that

$$N_H'(\alpha) = \varepsilon N_H \frac{\mu_H}{vr - \alpha\mu_H + \phi}.$$

Hence:

$$\begin{aligned}\beta'(\alpha) &= \frac{(\Lambda + r)Iv}{\Lambda N_H^2} N_H'(\alpha) = \frac{(\Lambda + r)Iv}{\Lambda N_H^2} \varepsilon N_H \frac{\mu_H}{vr - \alpha\mu_H + \phi} \\ &= \frac{(\Lambda + r)Iv}{\Lambda N_H} \frac{\varepsilon\mu_H}{vr - \alpha\mu_H + \phi} = (1 - \beta(\alpha)) \frac{\varepsilon\mu_H}{vr - \alpha\mu_H + \phi}\end{aligned}$$

One can directly calculate that

$$\frac{\partial}{\partial\alpha}(1-\beta)N_H = (1-\beta)N_H'(\alpha) - \beta'(\alpha)N_H(\alpha) = 0.$$

Next note that

$$\left(\beta v + \frac{(1-\alpha)\mu_H}{r}\right) N_H = S(\alpha) - (1-\beta)N_H(\alpha).$$

It follows that

$$\frac{\partial}{\partial\alpha}\left(\beta v + \frac{(1-\alpha)\mu_H}{r}\right) N_H = S'(\alpha)$$

implying that $\alpha^* = \bar{\alpha}$. ∎

B.2 Proof of Proposition 1

Proof. Claims 1 and 2 in Proposition 1 follow directly from the developments in the main text. We prove claims 3 and 4 in several steps. To derive claim 3, we first conjecture that the optimal securities are characterized by stationary payout structures and then verify that this is indeed the case. The proof makes use of the results presented in Appendix C.

Step I — Preliminaries

It is clear that the developers issue maximally two securities as there are only two investment motives. First, there is one token with cash flow rights α_t in that a fraction $\alpha_t \in [0,1]$ of dividends dD_t accrue to token holders. That is, the cash-flow of tokens equals $dD_t^T = \alpha_t dD_t$ The token serves as the transaction medium on the platform as characterized in the main text (Section 2). Second, we introduce another security—called E—with equilibrium price E_t that pays its holder $dD_t^E = \hat{\gamma}_t(1-\alpha_t)dD_t$ but does not serve as transaction medium. We normalize the supply of both securities to one and assume that developers possess at each point in time $\beta_t \in [0,1]$ tokens and $\gamma_t \in [0,1]$ units of the security E. This second security is akin to outside equity.

Securities must satisfy developers' and investors' limited liability, implying the constraints for all $t \geq 0$:

$$dD_t^T, dD_t^E \geq 0 \quad \text{and} \quad dD_t - dD_t^E - dD_t^T \geq 0$$

These constraints are satisfied if and only if: $\alpha_t, \hat{\gamma}_t \in [0,1] \; \forall \; t \geq 0$. Owing to $dD_t = 0$ for $t < \tau$, it readily follows that $dD_t^E = dD_t^T$ for $t < \tau$ so that the values $\hat{\gamma}_t, \alpha_t$ are irrelevant. We consider in Proposition 1 that the token serves as transaction medium; the case in which the token does not serve as platform transaction medium is analyzed in Section 5.

Step II — Problem

Developers maximize

$$V_0 = \max_{\{\alpha_t\},\{\beta_t\},\{\gamma_t\},\{\hat{\gamma}_t\},\{a_t\}} \mathbb{E}\left[\int_0^\infty e^{-rt}(-P_t\, d\beta_t - E_t d\gamma_t + dD_t - dD_t^E - dD_t^T - \kappa a_t dt)\right] - I, \quad (35)$$

subject to

$$(1-\beta)P_0 + (1-\hat{\gamma}_0)E_0 \geq I. \quad (36)$$

Developers have the same preferences for holding any security as platform users. Thus, There are no gains from trade over $(0,\tau)$ so that developers sell securities only at time 0, to cover financing needs, or after time τ.

Because the security E is held by investors with preferences identical to those of developers, there is no loss in generality in setting $\hat{\gamma}_t = 1$. This is because the control γ_t is enough to implement any profit sharing between developers and the holders of security E.

Step III — Pricing

We conjecture that α, γ are stationary and that developers do not trade securities after time τ. That is:

$$d\alpha_t = d\hat{\gamma}_t = 0 \; \forall \; t \geq 0 \quad (37)$$

and

$$d\beta_t = d\gamma_t = 0 \;\forall\; t \geq \tau. \tag{38}$$

Under this conjecture the token is priced, as described in the main text. The security E is priced by investors with the same preferences as developers. Under this conjecture, E is just a conventional equity claim on the startup's cash flows with value given by:

$$E_t = E_\tau = \frac{(1-\alpha)N_H\mu_H}{r}$$

for $t \geq \tau$ and for $t < \tau$:

$$E_t = \frac{\Lambda E_\tau}{r+\Lambda}.$$

Given the prices derived under stationarity, it is clear that developers' motive to trade securities is the same for each $t \geq \tau$. Hence, for any $t \geq \tau$, developers are at their optimal securities holdings in that they either sell securities at time τ or never, thereby confirming the conjectured trading behavior (38). Given this trading behavior, the expressions for the prices P and E and the productivity process A, Proposition 6 and arguments from the main text show that constant γ and constant α are indeed optimal, thereby confirming (37). This proves claim 3 of Proposition 1.

Step IV

The fact that γ and $\hat{\gamma}$ are constant at the optimum also implies that any security that is— at the optimum—issued next to tokens is an equity claim. It therefore suffices to consider securities with $\hat{\gamma} = 1$, i.e., startup equity. This implies that claim 4 of Proposition 1 follows from Proposition 6 (see Appendix C). The proof is now complete. □

B.3 Proof of Proposition 2

The proof is split in two parts. Part I derives $\bar{\alpha}$ that maximizes $S(\alpha)$ and Part II shows that $\bar{\alpha}$ is optimal even if $I > 0 \Leftrightarrow \beta < 1$.

B.3.1 Part I

Proof. Take any α, μ and denote the user-base as a function of μ and α by $N(\alpha)$. Define $\varepsilon := 1/(1-\eta-\xi) \geq 1$. Assume first that the token is priced as a utility token in that $vr - \mu\alpha > 0$. We then have:

$$\begin{aligned}
S'(\alpha) &= \left(v + \frac{(1-\alpha)\mu}{r}\right) N'(\alpha) - \frac{\mu}{r}N(\alpha) \\
&= \varepsilon \left(v + \frac{(1-\alpha)\mu}{r}\right) N(\alpha)\frac{\mu}{vr - \mu\alpha + \phi} - \frac{\mu}{r}N(\alpha) \\
&\propto \varepsilon\left(vr + (1-\alpha)\mu\right)\frac{\mu}{vr-\mu\alpha+\phi} - \mu \propto \varepsilon vr + \varepsilon(1-\alpha)\mu - vr + \mu\alpha - \phi \\
&= v(\varepsilon - 1)r + \varepsilon\mu - \alpha(\varepsilon-1)\mu - \phi \propto vr + \frac{\mu}{\xi} - \alpha\mu - \frac{(1-\xi)\phi}{\xi}.
\end{aligned}$$

We can calculate the α that solves the FOC $S'(\alpha) = 0$:

$$\alpha = \frac{vr}{\mu} + \frac{1}{\xi} - \frac{\phi(1-\xi)}{\xi\mu}.$$

If this α were a minimum rather than a maximum, then $S'(0), S'(1) \leq 0$, which would readily imply that $S'(\alpha) < 0$ for all $\alpha \geq 0$ and that $\bar{\alpha} = 0$; in particular, the above expression for α would be negative in this case.

Optimal α must lie in $[0,1]$ implying that

$$\frac{vr}{\mu} + \frac{1}{\xi} - \frac{\phi(1-\xi)}{\xi\mu} \geq 1 \Longrightarrow \bar{\alpha} = 1, \tag{39}$$

in which case $S'(1) \geq 0$, and

$$\frac{vr}{\mu} + \frac{1}{\xi} - \frac{(1-\xi)\phi}{\xi\mu} \leq 0 \Longrightarrow \bar{\alpha} = 0,$$

in which case $S'(0) \leq 0$. Otherwise, we have that

$$\bar{\alpha} = \frac{vr}{\mu} + \frac{1}{\xi} - \frac{\phi(1-\xi)}{\xi\mu}.$$

If interior, the first-best adoption level equals (for $\mu = \mu_H$)

$$N_H^{FB} = \left(\frac{A_H\xi}{\phi - \mu_H}\right)^{\frac{1}{1-\xi}}$$

and the maximized surplus is given by

$$S^{FB} = \left(\frac{(1-\xi)(\phi - \mu_H)}{r\xi}\right) N_H^{FB}.$$

□

B.3.2 Part II

Proof. By assumption, the incentive condition (14) is not relevant for the maximization. The claim follows then from Lemma 1. □

B.4 Proof of Proposition 3

B.4.1 Part I

Let us start with the analysis of the optimal level of security features α.

Proof. If the incentive condition is not relevant, as is the case for I or κ or $1/\Lambda$ sufficiently small, then $\alpha = \bar{\alpha}$. This is the first claim of the Proposition.

More generally, any value of α that maximizes $IC(\alpha)$ and $S(\alpha)$ is optimal. We show now that, if $\mu_H = \mu_L$, $\alpha = \bar{\alpha}$ maximizes $IC(\alpha)$, which proves the second claim of the Proposition. To do so, define:

$$\mathcal{I}(A) := \frac{\partial}{\partial A}\left(\beta v + \frac{(1-\alpha)\mu(A)}{r}\right) N(A) = \frac{(1-\alpha)\mu'(A)N(A)}{r} + \left(\beta v + \frac{(1-\alpha)\mu(A)}{r}\right) N'(A).$$

It is clear that $N'(A), N''(A) > 0$ if $\xi > 0$ in that $N(A)$ is increasing and convex in A. Note that in order to maximize $IC(\alpha)$ over α it suffices to maximize $\mathcal{I}(A)$ for all A over α. Formally:

$$\alpha' = \arg\max_{\alpha} \ \mathcal{I}(A) \ \forall \ A > 0 \implies \alpha' = \arg\max_{\alpha} \ IC(\alpha).$$

We start by calculating

$$\begin{aligned} N'(A) &= \frac{1}{1-\xi}\left(\frac{A}{vr - \alpha\mu(A) + \phi}\right)^{\frac{1}{1-\xi}-1} \frac{(vr - \alpha\mu(A) + \phi) + A\alpha\mu'(A)}{(vr - \alpha\mu(A) + \phi)^2} \\ &= \frac{N(A)}{1-\xi}\left(\frac{1}{A} + \frac{\alpha\mu'(A)}{vr - \alpha\mu(A) + \phi}\right). \end{aligned}$$

If now $\mu'(A) = 0$ and $\mu_H = \mu_L$, then:

$$\mathcal{I}(A) = \left(\beta v + \frac{(1-\alpha)\mu(A)}{r}\right) \frac{N(A)}{(1-\xi)A} \propto \left(\beta v + \frac{(1-\alpha)\mu(A)}{r}\right) N(A).$$

Define

$$\alpha_0(A) = \arg\max_{\alpha} \left(\beta v + \frac{(1-\alpha)\mu(A)}{r}\right) N(A).$$

By the previous part it is clear that $\alpha_0(A_H) = \bar{\alpha}$ and by Lemma 1 that $\alpha_0(A)$ maximizes the surplus

$$S(\alpha|A) = \left(v + \frac{(1-\alpha)\mu(A)}{r}\right) N(A),$$

with $S(\alpha) = S(\alpha|A_H)$. On the other hand, Proposition 2 shows that the optimal $\bar{\alpha}$ does not depend on A_H implying that $\bar{\alpha} = \arg\max_\alpha S(\alpha|A)$ for any $A > 0$. It readily follows that $\alpha_0(A) = \bar{\alpha}$ for any A, which concludes the proof. □

B.4.2 Part II

We prove the claims regarding the optimal retention level β (for κ, I and Λ). The claims regarding the network effects parameter follow in Part III.

Proof. To start with, note that:

$$\frac{\partial P_H}{\partial \alpha} = \frac{v\mu_H}{(vr - \alpha\mu_H + \phi)(1-\xi)} N_H > 0.$$

Likewise, $S'(\alpha) > 0$ for all $\alpha \in [0, 1]$ owing to $\bar{\alpha} = 1$. That is:

$$\frac{dP_H}{dS(\alpha)} > 0.$$

Next, take the financing constraint (4) in that:

$$\beta = 1 - \frac{I}{P_H}\frac{r+\Lambda}{\Lambda}.$$

We have that β strictly decreases in I if P_H decreases in I. If P_H was strictly increasing in I then, due to $dP_H/dS(\alpha) > 0$, $S(\alpha)$ would also be increasing in I. Hence, there would exist $I_1 < I_2$ with

$$S(\alpha(I_2)|I_2) > S(\alpha(I_1)|I_1),$$

where $\alpha(\cdot)$ denotes the optimal α under the parameter configuration with I_i. As $S(\alpha)$ does not depend on I, it follows that $\alpha(I_1)$ cannot be optimal, which is a contradiction. As a result, it must be that $\frac{d\beta}{dI} < 0$. Essentially the same argument immediately implies that $\frac{d\beta}{d\Lambda} > 0$.

Next, note that:

$$\frac{d\beta}{d\kappa} < 0 \Longleftrightarrow \frac{dP_H}{d\kappa} < 0 \Longleftrightarrow \frac{dS(\alpha)}{d\kappa} < 0,$$

where the first equivalence follows from the financing constraint (4) and the second from previous arguments. Assume to the contrary that there exist $\kappa_1 < \kappa_2$ with

$$S(\alpha(\kappa)|\kappa_2) > S(\alpha(\kappa_1)|\kappa_1),$$

where $\alpha(\cdot)$ denotes the optimal α under the parameter configuration with κ_i. Since $S(\alpha)$ does not depend on κ, it follows that $\alpha(\kappa_1)$ cannot be optimal, which is a contradiction. Hence, $S(\alpha)$ must decrease in κ. Note that $S(\alpha)$ is single-peaked, i.e., has a unique maximum, on $[0, 1]$. Thus, if the incentive condition is tight, in which case $\frac{d\alpha}{d\kappa} \neq 0$, it is clear that β must strictly decrease in κ. □

B.4.3 Part III

This part proves all claims regarding the network effects parameter ξ.

Proof. Note that:

$$N_H = \left(\frac{A_H}{vr + \phi - \alpha\mu_H}\right)^{\frac{1}{1-\xi}} \geq \left(\frac{A_H}{vr+\phi}\right)^{\frac{1}{1-\xi}} \geq 1,$$

where the second inequality uses the parameter assumption $A_H \geq vr + \phi$. In addition, due to $N_H \geq 1$, it follows that N_H increases in ξ and so does $P_H = vN_H$. Hence, β increases in ξ. Next, note that:

$$\frac{\partial N_H}{\partial \xi} = N_H \ln(N_H)\frac{1}{(1-\xi)^2} > N_L \ln(N_L)\frac{1}{(1-\xi)^2} = \frac{\partial N_L}{\partial \xi}.$$

Taking

$$IC(\alpha) = \Lambda\left(\beta v + \frac{(1-\alpha)\mu_H}{r}\right)N_H - \kappa - \Lambda\left(\beta v + \frac{(1-\alpha)\mu_L}{r}\right)N_L,$$

it follows that

$$\begin{aligned}\frac{\partial IC(\alpha)}{\partial \xi} &= \Lambda v \frac{\partial \beta}{\partial \xi}(N_H - N_L) + \Lambda \beta v\left(\frac{\partial N_H}{\partial \xi} - \frac{\partial N_L}{\partial \xi}\right) + \frac{\Lambda(1-\alpha)\mu_H}{r}\frac{\partial N_H}{\partial \xi} - \frac{\Lambda(1-\alpha)\mu_L}{r}\frac{\partial N_L}{\partial \xi} \\ &> \Lambda v\frac{\partial \beta}{\partial \xi}(N_H - N_L) + \Lambda(\beta v + (1-\alpha)\mu_L/r)\left(\frac{\partial N_H}{\partial \xi} - \frac{\partial N_L}{\partial \xi}\right) > 0,\end{aligned}$$

where the first inequality uses $\mu_H > \mu_L$ and the second follows from our previous derivations. The claim regarding β is proven by mimicking the argument in the proof of Proposition 3 (Part II), and using the fact that $S(\alpha)$ strictly increases in ξ due to $A_H \geq vr + \phi$. In fact:

$$\frac{\partial S(\alpha)}{\partial \xi} > 0 \Longleftarrow A_H > vr + \phi.$$

It becomes clear that $\frac{\partial IC(\alpha)}{\partial \xi} > 0$ as $\frac{dS(\alpha)}{d\xi} > 0$, implying that P_H and β increase in ξ. $\square$

B.5 Proof of Corollary 1

The first part establishes an auxiliary result. The second part proves the claim regarding financing needs while the third part proves the claim regarding the agency frictions.

B.5.1 Part I

Lemma 2. *The optimal token velocity* $v^* = \arg\max_v S(\alpha)$ *is given by:*

$$v^* = v^*(\alpha) = \max\left\{\frac{(1-\xi)\phi - \mu_H(1-\xi\alpha)}{r\xi}, \frac{\alpha\mu_H}{r}\right\}.$$

The surplus is given by:

$$S^{FB} = \max\left\{\left(\frac{\xi}{\phi-\mu}\right)^{\frac{\xi}{1-\xi}} \frac{(1-\xi)A^{\frac{1}{1-\xi}}}{r}, \frac{\mu_H}{r}\left(\frac{A_H}{\phi}\right)^{\frac{1}{1-\xi}}\right\}$$

and does not depend on α*.*

Proof. The proof is split in two parts, which considers different cases of the parameter values.

1. First, let us focus on the case where $vr > \mu_H\alpha$. Define $\varepsilon = 1/(1-\xi)$. The surplus is given by:

   $$S(\alpha)\left(v + \frac{(1-\alpha)\mu_H}{r}\right)N_H,$$

   so that:

   $$\begin{aligned}\frac{\partial S(\alpha)}{\partial v} &= N_H - \left(v + \frac{(1-\alpha)\mu_H}{r}\right)\frac{\partial N_H}{\partial v} \\ &= N_H - \left(v + \frac{(1-\alpha)\mu_H}{r}\right)\varepsilon N_H \frac{r}{vr - \mu\alpha + \phi} \propto 1 - \frac{vr + (1-\alpha)\mu_H}{vr - \mu\alpha + \phi}\varepsilon.\end{aligned}$$

   Hence, v^* solving $\frac{\partial S(\alpha)}{\partial v} = 0$ is given by:

   $$0 = v^*r - \mu\alpha + \phi = v^*r\varepsilon + (1-\alpha)\mu_H\varepsilon \Longrightarrow v^*r(\varepsilon - 1) = \phi - \mu_H\alpha - (1-\alpha)\mu_H\varepsilon$$

   We thus have:

   $$v^* = v^*(\alpha) = \frac{\phi - \mu_H(\alpha + (1-\alpha)\varepsilon)}{(\varepsilon-1)r} = \frac{\mu_H\alpha}{r} + \frac{\phi - \mu_H}{r\xi} - \frac{\phi}{r}$$

so that

$$v^* r = \mu_H \alpha + \frac{\phi - \mu_H}{\xi} - \phi,$$

implying that:

$$N_H = \left(\frac{A\,\xi}{\phi - \mu} \right)^{\frac{1}{1-\xi}}.$$

The maximized surplus equals:

$$S^{FB} = \left(v^* + \frac{(1-\alpha)\mu_H}{r} \right) N_H = \frac{(\phi - \mu)\,(1-\xi)}{r\,\xi} \left(\frac{A\,\xi}{\phi - \mu} \right)^{\frac{1}{1-\xi}} = \left(\frac{\xi}{\phi - \mu} \right)^{\frac{\xi}{1-\xi}} \frac{(1-\xi) A^{\frac{1}{1-\xi}}}{r}$$

and so does not depend on α. Last, we argue that v^* is indeed a maximum. If it were not, then either $v \to 0$ or $v \to \infty$ yields higher payoff. Clearly, $v \to \infty$ leads to platform value zero, as $\xi > 0$. The case $v \to 0$ is discussed below.

2. If $\mu_H \alpha > vr$, the token is priced according to its security features and the exact value $v \in [0, \mu_H \alpha / r)$ becomes irrelevant for $S(\alpha), N_H$ and the developers' payoff. Under these circumstances, the surplus becomes:

$$S^{FB} = \frac{\mu_H f}{r} \left(\frac{A_H}{\phi} \right)^{\frac{1}{1-\xi}}.$$

Combining of the two cases leads to the expressions stated in the Proposition. □

B.5.2 Part II

Proof. By Lemma 2

$$v^* = v^*(\alpha) = \max \left\{ \frac{(1-\xi)\phi - \mu_H(1-\xi\alpha)}{r\xi}, \frac{\alpha \mu_H}{r} \right\}.$$

Hence, $v < \mu_H \alpha$ does not maximize the overall surplus if and only

$$\frac{(1-\xi)\phi - \mu_H(1-\xi\alpha)}{r\xi} > \frac{\alpha \mu_H}{r},$$

which can be simplified to

$$(1-\xi)\phi > \mu_H,$$

thereby concluding the proof. □

B.5.3 Part III

Proof. Taking

$$N_H = \left(\frac{A_H}{vr + \phi - \alpha \mu_H} \right)^{\frac{1}{1-\xi}},$$

it follows that

$$\frac{\partial N_H}{\partial v} = N_H \frac{r}{\xi (vr + \phi - \alpha \mu_H)} > N_L \frac{r}{\xi (vr + \phi - \alpha \mu_L)} = \frac{\partial N_L}{\partial v}.$$

Clearly, $\frac{\partial N_i}{\partial v} < 0$ for $i = H, L$. Notably:

$$\frac{\partial P_H}{\partial v} \propto (1-\xi)(\phi - \alpha\mu_H) - \xi v r$$

and for $\beta = 1 - \frac{(r+\Lambda)I}{\Lambda P_H}$:

$$\frac{\partial(v\beta)}{\partial v} = \beta + v\frac{(r+\Lambda)I}{\Lambda P_H^2}\frac{\partial P_H}{\partial v} = \beta + v(1-\beta)\frac{\partial P_H/\partial v}{P_H}.$$

It is clear that $\frac{\partial(\beta v)}{\partial v} < 0$ if v is sufficiently large and I is sufficiently large (so that β is close to zero). Taking

$$IC(\alpha) = \Lambda\left(\beta v + \frac{(1-\alpha)\mu_H}{r}\right)N_H - \kappa - \Lambda\left(\beta v + \frac{(1-\alpha)\mu_L}{r}\right)N_L,$$

it follows that

$$\begin{aligned}\frac{\partial IC(\alpha)}{\partial v} &\propto v\frac{\partial \beta}{\partial v}(N_H - N_L) + \beta v\left(\frac{\partial N_H}{\partial v} - \frac{\partial N_L}{\partial v}\right) + \frac{(1-\alpha)\mu_H}{r}\frac{\partial N_H}{\partial v} - \frac{(1-\alpha)\mu_L}{r}\frac{\partial N_L}{\partial v} \\ &\quad + \beta(N_H - N_L) \\ &< \frac{\partial(\beta v)}{\partial v}(N_H - N_L) + \left(\beta v + \frac{(1-\alpha)\mu_H}{r}\right)\left(\frac{\partial N_H}{\partial v} - \frac{\partial N_L}{\partial v}\right) < 0,\end{aligned}$$

where the penultimate inequality uses $\frac{\partial(\beta v)}{\partial v} < 0$ and the last one our previous derivations. The claim regarding β is proven by mimicking the argument in the proof of Proposition 3 (Part II), upon noticing that $S(\alpha)$ strictly decreases in v for v sufficiently large, which follows by continuity as $\lim_{v\to\infty} S(\alpha) = 0$.

In contrast, if v is sufficiently small and $\mu_H \geq \mu_L$ is sufficiently small to ensure $vr \geq \mu_H\alpha$ then:

$$\begin{aligned}\frac{\partial IC(\alpha)}{\partial v} &\propto o(v) + \frac{\mu_H(1-\alpha)}{r}\frac{\partial N_H}{\partial v} - \frac{\mu_L(1-\alpha)}{r}\frac{\partial N_L}{\partial v} + \beta(N_H - N_L) \\ &= \beta(N_H - N_L) + o(v) + o(\mu_H) > 0,\end{aligned}$$

for μ_H, v sufficiently small. The claim regarding β is proven by mimicking the argument in the proof of Proposition 3 (Part II), upon noticing that $S(\alpha)$ strictly increases in v for v sufficiently small, which—by the first part—is the case if $(1-\xi)\phi > \mu_H$. □

B.6 Proof of Corollary 2

Proof. Clearly an ICO with $\alpha = 0$ is optimal if $\bar{\alpha}$, which—by Proposition 2—is the case if and only if

$$vr\xi < (1-\xi)\phi - \mu_H.$$

Under these circumstances, $\alpha = 0$ leads to the maximal amount of equity incentives (ceteris paribus) and so—if it maximizes the overall surplus—must be optimal altogether. To see this, take a look at:

$$\mathcal{I}(A) := \frac{\partial}{\partial A}\left(\beta v + \frac{(1-\alpha)\mu(A)}{r}\right)N(A) = \frac{(1-\alpha)\mu'(A)N(A)}{r} + \left(\beta v + \frac{(1-\alpha)\mu(A)}{r}\right)N'(A).$$

By virtue of Lemma 1, the second term is maximized by $\alpha = 0 = \bar{\alpha}$ as $N'(A) \propto N(A)$. The first term has derivative wrt. α proportional to:

$$-N_H + \frac{N_H(1-\alpha)\mu_H}{(1-\xi)(vr - \mu_H\alpha + \phi)} \propto (1-\alpha)\mu_H - (1-\xi)(vr - \mu_H\alpha + \phi),$$

which is maximized for $\alpha = 0$. In this case, the the last line becomes

$$\mu_H - (1-\xi)(vr+\phi) = \mu_H - ((1-\xi)\phi - \xi vr) - vr < \mu_H - ((1-\xi)\phi - \xi vr) < 0,$$

where the last inequality follows from the fact that $\bar{\alpha}$ is optimal. Due to

$$\alpha' = \arg\max_{\alpha} \; \mathcal{I}(A) \; \forall \; A > 0 \implies \alpha' = \arg\max_{\alpha} \; IC(\alpha),$$

$\alpha = 0$ jointly maximizes surplus and incentives, therbey clearly being optimal.

Next, a STO with $\alpha > 0$ maximizes the overall surplus if

$$vr\xi > (1-\xi)\phi - \mu_H.$$

Then $\alpha > 0$ is also optimal if $IC(\alpha) \geq 0$, which is the case if κ is sufficiently small, $1/\Lambda$ is sufficiently small or I is sufficiently small by virtue of Assumption 2. Likewise, this is the case if $\mu_H = \mu_L$ in which case equity and token-based incentives are equivalent. □

B.7 Proof of Corollary 3

Proof. Consider $0 = \arg\max_{v^* \in \{0,v\}} S(\alpha)$. This maximization problem can be solved by comparing the payoff under a fiat-based platform (i.e., a token without utility features):

$$\frac{\mu_H}{r}\left(\frac{A_H}{\phi}\right)^{\frac{1}{1-\xi}}$$

with the payoff under a token-based platform for a given v and, by Assumption 1, the optimal value $\alpha = 1$:

$$v\left(\frac{A_H}{\phi + \max\{vr - \mu_H, 0\}}\right)^{\frac{1}{1-\xi}}.$$

Then, a fiat-based platform maximizes surplus over $v^* \in \{0, v\}$ if

$$v\left(\frac{A_H}{\phi + \max\{vr - \mu_H, 0\}}\right)^{\frac{1}{1-\xi}} \leq \frac{\mu_H}{r}\left(\frac{A_H}{\phi}\right)^{\frac{1}{1-\xi}},$$

which can be rearranged to (25):

$$\frac{\mu_H}{vr} \geq \left(\frac{\phi}{\max\{vr - \mu_H, 0\} + \phi}\right)^{\frac{1}{1-\xi}}.$$

Note that—owing to $\xi > 0$—(25) holds in the limit $v \to \infty$ and thus— by continuity—for v sufficiently large. Also note that a fiat based platform yields surplus $N_\tau \mu_H / r$ while a token based platform with $\alpha = 1$ yields payoff $N_\tau v$. Because of $vr \geq \mu_H$, the fiat based platform must therefore induce a higher adoption level N than the token based platform with $\alpha = 1$ to be optimal.

Next, we derive the stronger parameter condition that guarantees the optimality of a fiat-based platform. To do so, we take the optimal value v^* from Lemma 1:

$$v^* = v^*(\alpha) = \max\left\{\frac{(1-\xi)\phi - \mu_H(1-\xi\alpha)}{r\xi}, \frac{\alpha\mu_H}{r}\right\}.$$

Note that all values $v \leq \alpha\mu/r$ are payoff-equivalent. Notably, any $v \leq \alpha\mu/r$ maximizes incentives since it leads to maximal equity-based incentives. Direct calculations yield then that $v^* \leq \mu_H\alpha/r$ is the case whenever $\phi(1-\xi) \leq \mu_H$. More precisely, by mimicking the argument presented in the proof of Corollary 2, one can show that once $v = 0$ maximizes the overall surplus $S(\alpha)$ it also maximizes incentives, implying that $v = 0$ is optimal once it maximizes the overall surplus.

Conversely, a token-based platform maximizes surplus if:

$$v\left(\frac{A_H}{\phi + \max\{vr - \mu_H, 0\}}\right)^{\frac{1}{1-\xi}} > \frac{\mu_H}{r}\left(\frac{A_H}{\phi}\right)^{\frac{1}{1-\xi}}$$

It is therefore optimal if the incentive condition (14) does not bind, which is the case if I, κ is sufficiently low. Likewise, equity and token-based incentives are equivalent if $\mu_H = \mu_L$. □

B.8 Proof of Corollary 4

Proof. First, consider the function for $\mu_H < vr$:

$$f(\mu_H) : \mu_H \mapsto \frac{\mu_H}{vr} - \left(\frac{\phi}{\max\{vr - \mu_H, 0\} + \phi}\right)^{\frac{1}{1-\xi}}.$$

This function is the sum of a linear part and a strictly concave part, and so $f''(\mu_H) < 0$ and $f(\mu_H)$ is strictly concave. As $f(vr) = 0$, the function has maximally one root on the interval $[0, vr)$, denoted by μ^* with $f(\mu^*) = 0$. Let $\mu^* = vr$ in case f does not have a root on $[0, vr)$. Calculate for $\mu < vr$:

$$f'(\mu) = \frac{1}{vr} - \frac{1}{1-\xi}\left(\frac{\phi}{\max\{vr - \mu, 0\} + \phi}\right)^{\frac{1}{1-\xi}} \frac{1}{\max\{0, vr - \mu\} + \phi},$$

which is evaluated at $\mu_H = vr$:

$$f'(vr) = \frac{1}{vr} - \frac{1}{(1-\xi)\phi}.$$

This has the same sign as:

$$(1-\xi)\phi - vr.$$

As a result, $f'(vr) < 0 \iff \mu^* < vr$ if and only if $(1-\xi)\phi < vr$, in which case the root μ^* is unique on $[0, vr)$. It therefore follows that $f(\mu_H) \geq 0$ for $\mu_H \in [\mu^*, vr)$. That is, there exists unique μ^* such that for $\mu_H \in [\mu^*, vr)$ a fiat-based platform is preferred to a token based platform with $\alpha = 1$.

By Proposition 2, a token based platform—given v—with $\alpha = 1$ is optimal if and only if:

$$\mu_H \geq \phi - \frac{\xi vr}{1-\xi}.$$

On the other hand (by Proposition 2), if

$$(1-\xi)\phi - \xi vr \leq \mu_H \leq \phi - \frac{\xi vr}{1-\xi},$$

then $\alpha^* \in [0,1]$ is the unconstrained optimum, in which case the maximal payoff is achieved. It is clear that under these circumstances, token based platform is optimal. As a result, $\mu^* \geq \phi - \frac{\xi vr}{1-\xi}$.

Conversely, if

$$\mu_H < (1-\xi)\phi - \xi vr,$$

an ICO with $\alpha = 0$ is optimal yielding surplus:

$$S_{ICO} = v\left(\frac{A_H}{vr+\phi}\right)^{\frac{1}{1-\xi}},$$

while a fiat-based platform yields payoff:

$$S_{Fiat} = \frac{\mu_H}{r}\left(\frac{A_H}{\phi}\right)^{\frac{1}{1-\xi}},$$

By the previous step, we know that in the limit $\mu_H \to (1-\xi)\phi - \xi vr$: $S_{ICO} \geq S_{Fiat}$ while it is apparent that this must be the case for lower $\mu_H \in [0, (1-\xi)\phi - \xi vr)$ too. Hence, a token based platform with $\alpha = 0$ is preferred for a fiat based platform if $\mu_H \in [0, (1-\xi)\phi - \xi vr)$.

Thus, there exists unique $\bar{I}^{\mu_H} \in (\phi - vr\xi/(1-\xi), \phi(1-\xi)]$ such that an ICO (i.e., $\alpha = 0, v^* = v$) is optimal if $\mu_H \in I^{\mu_H}_{ICO}$, an STO (i.e., $\alpha > 0, v^* = v$) is optimal if $\mu_H \in I^{\mu_H}_{STO}$ and a token without utility features (i.e., $v^* = 0$) is optimal if $\mu_H \in I^{\mu_H}_{Fiat}$ where

$$I^{\mu_H}_{ICO} := [0, (1-\xi)\phi - vr\xi); I^{\mu_H}_{STO} := [(1-\xi)\phi - vr\xi, \bar{I}^{\mu_H}); I^{\mu_H}_{Fiat} := [\bar{I}^{\mu_H}, \infty).$$

Applying the same arguments again, we likewise obtain that there exists unique $\bar{I}^{\xi} \in \left(\frac{\phi-\mu_H}{vr+\phi-\mu_H}, 1\right)$ such that an ICO (i.e., $\alpha = 0, v^* = v$) is optimal if $\xi \in I^{\xi}_{ICO}$, an STO (i.e., $\alpha > 0, v^* = v$) is optimal if $\xi \in I^{\xi}_{STO}$ and a token without utility features (i.e., $v^* = 0$) is optimal if $\xi \in I^{\xi}_{Fiat}$ where

$$I^{\xi}_{ICO} := \left[0, \frac{\phi-\mu_H}{vr+\phi}\right); I^{\xi}_{STO} := \left[\frac{\phi-\mu_H}{vr+\phi}, \bar{I}^{\xi}\right); I^{\xi}_{Fiat} := [\bar{I}^{\xi}, 1).$$

□

B.9 Proof of Proposition 4

B.9.1 Part I

Proof. We prove the claim for $I = \kappa = 0$. Define $\varepsilon = 1/(1-\xi)$. Note that

$$N_H = \left(\frac{A_H}{\max\{0, vr - \alpha(\mu_H + f)\} + \phi + f}\right)^{\frac{1}{1-\xi}} \tag{40}$$

and that the optimal fee is such that:

$$f^* = \arg\max_{f\geq 0}(\mu_H + f)N_H.$$

It therefore solves that the optimal fee — without any constraints imposed — must solve the FOC $\frac{\partial(\mu_H+f)N_H}{\partial f} = 0$.

1. Assume that $vr - \alpha(\mu_H + f) > 0$. Hence:

$$0 = \frac{\partial(\mu_H + f)N_H}{\partial f} = N_H - (\mu_H + f)\frac{\partial N_H}{\partial f} = N_H - \frac{\varepsilon N_H(1-\alpha)(\mu_H + f)}{vr - \alpha\mu_H + \phi + f(1-\alpha)}$$
$$\propto vr - \alpha\mu_H + \phi + f(1-\alpha) - \varepsilon(1-\alpha)(\mu_H + f).$$

Hence:

$$(1-\alpha)(\varepsilon - 1)f = vr + \phi - (1-\alpha)\mu_H\varepsilon - \alpha\mu_H$$
$$\iff (1-\alpha)f = \frac{(vr+\phi)(1-\xi) - \mu_H}{\xi} + \alpha\mu_H.$$

It therefore solves $\frac{\partial(\mu_H+f)N_H}{\partial f} = 0$. Assume that $vr \geq \alpha\mu_H$. Hence:

$$0 = \frac{\partial(\mu_H + f)N_H}{\partial f} = N_H - (\mu_H + f)\frac{\partial N_H}{\partial f} = N_H - \frac{\varepsilon N_H(1-\alpha)(\mu_H + f)}{vr - \alpha\mu_H + \phi + f(1-\alpha)}$$
$$\propto vr - \alpha\mu_H + \phi + f(1-\alpha) - \varepsilon(1-\alpha)(\mu_H + f).$$

Hence:

$$(1-\alpha)(\varepsilon - 1)f = vr + \phi - (1-\alpha)\mu_H\varepsilon - \alpha\mu_H$$
$$\iff (1-\alpha)f = \frac{(vr+\phi)(1-\xi) - \mu_H}{\xi} + \alpha\mu_H.$$

Note that $\varepsilon - 1 = \xi/(1-\xi)$ so that $\varepsilon/(\varepsilon - 1) = 1/\xi$. Notably, it must be that the derived expression for f is a maximum rather than a minimum since

$$\frac{\partial(\mu_H + f)N_H}{\partial f}|_{f=\bar{f}} \propto vr - \alpha\mu_H + \phi + f(1-\alpha) - \varepsilon(1-\alpha)(\mu_H + f)$$

and the RHS increases in f.

Plugging into (26) yields the desired expression of platform adoption

$$\left(\frac{A\xi}{vr + \phi - \mu_H}\right)^{\frac{1}{1-\xi}}$$

and payoff (surplus)

$$\left(v + \frac{(1-\xi)(vr + \phi - \mu_H)}{\xi r}\right)\left(\frac{A_H\xi}{\phi + vr - \mu_H}\right)^{\frac{1}{1-\xi}},$$

that notably do not depend explicitly on α.

2. Next, we assume that $vr \leq \alpha(\mu_H + f)$, implying that:

$$N_H = \left(\frac{A_H}{\phi + f}\right)^{\frac{1}{1-\xi}}.$$

Then, if $vr < \alpha(\mu_H + f)$, we can utilize the FOC to calculate

$$0 = N_H - \varepsilon\frac{\mu_H + f}{\phi + f}N_H \propto 1 - \varepsilon\frac{\mu_H + f}{\phi + f} \implies f = \frac{\phi - \varepsilon\mu_H}{\varepsilon - 1} = \frac{(1-\xi)\phi - \mu_H}{\xi}.$$

Otherwise, if $vr = \alpha(\mu_H + f)$, then

$$f = \frac{vr}{\alpha} - \mu_H = \frac{vr - \alpha\mu_H}{\alpha}.$$

Altogether:

$$f^* = \max\left\{vr - \alpha\mu_H\alpha, \frac{(1-\xi)\phi - \mu_H}{\xi}\right\}.$$

In sum, we have shown that:

$$f^* = \min\left\{\frac{(1-\xi)(vr+\phi) - \mu_H}{\xi(1-\alpha)} + \alpha\mu_H, \max\left\{\frac{(1-\xi)\phi - \mu_H}{\xi}, \frac{vr}{\alpha} - \mu_H\right\}\right\}.$$

Next, note that:

$$\frac{(1-\xi)\phi - \mu_H}{\xi} < \frac{vr}{\alpha} - \mu_H \impliedby (1-\xi)(\phi - \mu_H) < vr\xi,$$

which is implied by Assumption 1. Thus:

$$f^* = \min\left\{\frac{(1-\xi)(vr+\phi) - \mu_H}{\xi(1-\alpha)} + \alpha\mu_H, \frac{vr}{\alpha} - \mu_H\right\}.$$

Clearly, the first expression in the "min" increases in α while the second one decreases; furthermore, if $(1-\xi)(vr+\phi) \geq \mu_H$ the first expression tends to ∞ while the second one is always positive (due to $vr \geq \mu_H$) and tends to ∞ as $\alpha \to 0$. Hence, if $(1-\xi)(vr+\phi) > \mu_H$, there exists a unique cutoff $\alpha_1 \in (0,1)$ solving

$$\frac{(1-\xi)(vr+\phi) - \mu_H}{\xi(1-\alpha)} + \alpha\mu_H = \frac{vr}{\alpha} - \mu_H.$$

Hence, below α_1, the payoff does not depend on α. Else, if $(1-\xi)(vr+\phi) \leq \mu_H$, then $\alpha_1 = 1$. □

B.10 Proof of Corollary 5

We make a parameter assumption (similar to Assumption 1) in order to ensure positive NPV and feasible incentive compatibility.

Assumption 3. *Parameters are such that*

$$\left(\beta v + \frac{(1-\xi)(vr+\phi-\mu_H)}{\xi r}\right)\left(\frac{A_H\xi}{\phi+vr-\mu_H}\right)^{\frac{1}{1-\xi}} > \left(\beta v + \frac{(1-\xi)(vr+\phi-\mu_L)}{\xi r}\right)\left(\frac{A_L\xi}{\phi+vr-\mu_L}\right)^{\frac{1}{1-\xi}} + \frac{\kappa}{\Lambda}$$

with:

$$\beta = 1 - \frac{I}{v}\left(\frac{A_H\xi}{\phi+vr-\mu_H}\right)^{\frac{-1}{1-\xi}}. \tag{41}$$

Proof. We consider now two cases separately:

1. First, assume that

$$f^* = \frac{vr}{\alpha} - \mu_H,$$

which implies the adoption level

$$N_H = \left(\frac{A_H}{vr/\alpha - \mu_H + \phi}\right)^{1/(1-\xi)}$$

and the price

$$P_H = \frac{\alpha(\mu_H + f)N_H}{r} = vN_H, \tag{42}$$

and so the overall surplus is

$$S(\alpha) = vP_H + (1-\alpha)\frac{\mu_H + f}{r}N_H \left(v + (1-\alpha)\frac{v}{\alpha}\right) N_H.$$

Next, for $\alpha > 0$:

$$\begin{aligned} S'(\alpha) &= -\frac{v}{\alpha}N_H - \frac{(1-\alpha)v}{\alpha^2}N_H + \left(v + (1-\alpha)\frac{v}{\alpha}\right) N_H'(\alpha) \\ &\propto -v\alpha - (1-\alpha)v + \varepsilon \left(v + (1-\alpha)\frac{v}{\alpha}\right) \frac{vr}{vr/\alpha - \mu_H + \phi} \\ &\propto -v\alpha + \frac{\varepsilon v^2 r}{vr/\alpha - \mu_H + \phi} \\ &\propto -1 + \frac{\varepsilon vr}{vr + \alpha(\phi - \mu_H)}. \end{aligned}$$

Hence, $S'(\alpha) = 0$ is solved by:

$$\varepsilon vr = vr + \alpha(\phi - \mu_H) \Longleftrightarrow \alpha = \frac{\xi vr}{(1-\xi)(\phi - \mu_H)}.$$

Let us now continue assuming that $\alpha \in (0, 1]$. Plugging in this value into the adoption formula yields

$$N_H = \left(\frac{A_H \xi}{\phi - \mu_H}\right)^{\frac{1}{1-\xi}}$$

and surplus

$$S(\alpha) = \left(v + (1-\alpha)\frac{v}{\alpha}\right) N_H.$$

Otherwise

$$vr \geq \frac{(1-\xi)(\phi - \mu_H)}{\xi} \Longrightarrow \alpha = 1$$

and

$$\mu_H \geq \phi \Longrightarrow \alpha = 0.$$

Notably, Assumption 1 implies that $\alpha = 1$, leading to adoption

$$N_H = \left(\frac{A_H}{\phi + vr - \mu_H}\right)^{\frac{1}{1-\xi}}$$

payoff (surplus)

$$v\left(\frac{A_H}{\phi+vr-\mu_H}\right)^{\frac{1}{1-\xi}}$$

Note that in the limit $\alpha \to 1$ indeed $f^* = vr - \mu_H$. Let us look at the incentive condition $IC \geq 0$ for any α:

$$IC \propto \left(\beta vr + \frac{v(1-\alpha)}{\alpha}\right) N_H - \left(\beta vr + \frac{v(1-\alpha)}{\alpha}\right) N_L.$$

Define

$$\mathcal{I}(A) := \frac{\partial}{\partial A}\left(\beta v + \frac{(1-\alpha)v/\alpha}{r}\right) N(A) = \frac{\partial}{\partial A}\left(\beta v + \frac{(1-\alpha)v/\alpha}{r}\right) N'(A).$$

It is clear that $N'(A), N''(A) > 0$ if $\xi > 0$ in that $N(A)$ is increasing and convex in A. Note that in order to maximize $IC(\alpha)$ over α it suffices to maximize $\mathcal{I}(A)$ for all A over α. Formally:

$$\alpha' = \arg\max_{\alpha}\ \mathcal{I}(A)\ \forall\ A > 0 \implies \alpha' = \arg\max_{\alpha}\ IC(\alpha).$$

As $N'(A) \propto N(A)$ it follows that

$$\mathcal{I}(A) \propto S(\alpha),$$

implying that incentives are maximized for $\alpha = 1$, which maximizes $S(\alpha)$. Hence, $\alpha = 1$ is optimal owing to Assumption 1.

2. Second, we consider

$$f^* = \frac{(1-\xi)(vr+\phi)-\mu_H}{\xi(1-\alpha)} + \alpha\mu_H$$

In this case, the payoff does not depend on α (see previous results). Likewise, β does not depend on α. Consider the off-equilibrium state $A_t = A_L$ and assume that in this case the optimal fee is

$$f_L^* = \frac{(1-\xi)(vr+\phi)-\mu_L}{\xi(1-\alpha)} + \alpha\mu_L.$$

Under these circumstances, the off-equilibrium payoff does not depend on α, given strategic, dynamic fee setting. Combining yields that the incentive condition (14) does not depend on α either. By our parameter assumption 2, we have that (14) is satisfied for $\alpha = 0$. It follows that the limit case $\alpha = 0$ is optimal. The expression for f^* immediately reveals that

$$f^* = \frac{(1-\xi)(vr+\phi)-\mu_L}{\xi(1-\alpha)}$$

under any parameterization. Likewise, f_L^* is the optimal fee off-equilibrium. This leads to adoption:

$$N_H = \left(\frac{A_L\xi}{\phi+vr-\mu_L}\right)^{\frac{1}{1-\xi}}$$

and payoff:

$$\left(v + \frac{(1-\xi)(vr+\phi-\mu_L)}{\xi r}\right)\left(\frac{A_L\xi}{\phi+vr-\mu_L}\right)^{\frac{1}{1-\xi}}.$$

3. Let us extend the argument for $\alpha \leq \alpha_1$. The payoff is the same as shown before for any $\alpha \leq \alpha_1$. Since the IC condition — by virtue of Assumption 2 — is met for $\alpha = 0$, we conclude that we always find $0 < \alpha \leq \alpha_2$ that is optimal if $\alpha = 0$ is optimal, which yields the desired condition.

In sum, we have shown that $\alpha \in \{0, 1\}$ is optimal. Note that $\alpha = 0$ is optimal if:

$$\begin{aligned}
&\left(v + \frac{(1-\xi)(vr + \phi - \mu_H)}{\xi r}\right)\left(\frac{A_H \xi}{\phi + vr - \mu_H}\right)^{\frac{1}{1-\xi}} \geq v \left(\frac{A_H}{\phi + vr - \mu_H}\right)^{\frac{1}{1-\xi}} \\
\iff &\left(v + \frac{(1-\xi)(vr + \phi - \mu_H)}{\xi r}\right) \xi^{\frac{1}{1-\xi}} \geq v \\
\iff &\left((1-\xi)(\phi - \mu_H) + vr\right) \xi^{\frac{\xi}{1-\xi}} \geq vr \\
\iff &(1-\xi)(\phi - \mu_H) + vr \geq vr \xi^{\frac{1-\xi}{\xi}}.
\end{aligned}$$

The above inequality is always satisfied if $\phi \geq \mu_H$ as $1 \geq \xi^{\frac{1-\xi}{\xi}} \Leftrightarrow 1 \geq \xi$.

Due to $\xi < 1$, it is clear that $N_H(1) > N_H(\alpha)\ \forall\ \alpha \leq \alpha_1$. □

B.11 Proof of Corollary 8

Proof. 1. Assume that $vr > (\mu_H + f)\alpha$. Under full commitment, developers choose the fee f in order to maximize (given α)

$$(\beta vr + (\mu_H + f)(1-\alpha))\left(\frac{A_H}{vr + \phi - \mu_H \alpha + (1-\alpha) f}\right)^{\frac{1}{1-\xi}}.$$

Define

$$N_H(f) = \left(\frac{A_H}{vr + \phi - \mu_H \alpha + (1-\alpha) f}\right)^{\frac{1}{1-\xi}}.$$

By Lemma 1, it suffices to solve for the fee f that maximizes $S(\alpha)$. Note that

$$\begin{aligned}
\frac{\partial S(\alpha)}{\partial f} &\propto (vr + (\mu_H + f)(1-\alpha)) N_H'(f) + (1-\alpha) N_H(f) \\
&\propto 1 - \frac{1}{1-\xi} \frac{(vr + (\mu_H + f)(1-\alpha))}{vr + \phi - \mu_H \alpha + (1-\alpha) f}.
\end{aligned}$$

We can solve for

$$(1-\alpha) f = \frac{\phi(1-\xi) - \mu_H - \xi vr}{\xi} + \alpha \mu_H,$$

leading to the adoption level

$$N_H^* = \left(\frac{A_H \xi}{\phi - \mu_H}\right)^{\frac{1}{1-\xi}}$$

It can be checked that the derived expression for f indeed constitutes a maximum rather than a minimum.

2. Next, assume $vr = (\mu_H + f)\alpha$. Then

$$f = \frac{vr}{\alpha} - \mu_H \text{ and } N_H^* = \left(\frac{A_H \xi}{\frac{vr}{\alpha} + \phi - \mu_H}\right)^{\frac{1}{1-\xi}}.$$

3. Last, assume $vr < (\mu_H + f)\alpha$. This implies that

$$N_H = \left(\frac{A_H}{\phi + f}\right)^{\frac{1}{1-\xi}} \quad \text{and } P_H = \frac{\alpha(\mu_H + f)N_H}{r}.$$

   We can wlog. assume that $\alpha = 1$. The FOC of maximization is

$$\frac{\partial S(\alpha)}{\partial f} \propto (\mu_H + f)N_H'(f) + N_H(f) \propto 1 - \frac{1}{1-\xi}\frac{\mu_H + f}{vr + f} = 0.$$

   We can solve for:

$$f = \frac{(1-\xi)\phi - \mu_H}{\xi}.$$

4. Overall, if $vr \leq \alpha(\mu_H + f)$, then

$$f^* = \min\left\{\frac{(1-\xi)(vr+\phi) - \mu_H}{\xi(1-\alpha)} + \alpha\mu_H, \frac{vr}{\alpha} - \mu_H\right\}.$$

   Because of

$$\frac{(1-\xi)\phi - \mu_H}{\xi} < \frac{vr}{\alpha} - \mu_H \Longleftarrow (1-\xi)(\phi - \mu_H) < vr\xi,$$

   we have that

$$f^* = \min\left\{\frac{(1-\xi)\phi - \xi vr - \mu_H}{\xi(1-\alpha)} + \alpha\mu_H, \frac{vr}{\alpha} - \mu_H\right\}.$$

Define $\alpha_2 \in (0,1)$ as the unique value solving:

$$\frac{(1-\xi)\phi - \xi vr - \mu_H}{\xi(1-\alpha)} + \alpha\mu_H = \frac{vr}{\alpha} - \mu_H \quad \text{for} \quad (1-\xi)\phi - \xi vr - \mu_H > 0.$$

Specifically, if $(1-\xi)\phi - \xi vr - \mu_H > 0$, the above equation possesses a unique solution on $(0,1)$; otherwise, we set $\alpha_2 = 1$. Either way, one can readily calculate (mimicking the argument from the proof of Proposition 5) that — given $\alpha \geq \alpha_2$ — $\alpha = 1$ is optimal.

Next, taking $\alpha = 1$, we compare the platform adoption levels under the two polar cases $\alpha = 0$ and $\alpha = 1$ for $\mathcal{X} \in \{\geq, \leq, <, >\}$:

$$\begin{aligned}\left(\frac{A_H\xi}{\phi - \mu_H}\right)^{\frac{1}{1-\xi}} \mathcal{X} \left(\frac{A_H}{vr + \phi - \mu_H}\right)^{\frac{1}{1-\xi}} &\Longleftrightarrow \frac{A_H\xi}{\phi - \mu_H} \mathcal{X} \frac{A_H}{vr + \phi - \mu_H} \\ &\Longleftrightarrow \frac{\xi}{\phi - \mu_H} \mathcal{X} \frac{1}{vr + \phi - \mu_H}.\end{aligned}$$

That is adoption under $\alpha = 1$ is higher than under $\alpha \leq \alpha_2$ if

$$\xi(vr + \phi - \mu_H) \leq \phi - \mu_H \Longleftrightarrow \xi vr \leq (\phi - \mu_H)(1-\xi).$$

□

B.12 Proof of Proposition 7

Proof. Last, we study when $\alpha \leq \alpha_2$ is optimal and when $\alpha = 1$ is optimal. It is easy to see that all values of $\alpha \leq \alpha_2$ yield the same payoff. Thus, it suffices to compare payoffs under the polar cases $\alpha = 0$ and $\alpha = 1$. Notably, $\alpha = 1$ is optimal if and only if:

$$\begin{aligned}
&\left(vr + \frac{(1-\xi)(\phi-\mu_H)-\xi vr}{\xi}\right)\left(\frac{A_H\xi}{\phi-\mu_H}\right)^{\frac{1}{1-\xi}} \leq vr\left(\frac{A_H}{vr+\phi-\mu_H}\right)^{\frac{1}{1-\xi}}\\
\iff\ &\frac{(1-\xi)(\phi-\mu_H)-\xi vr}{\xi vr} \leq \left(\frac{(\phi-\mu_H)\xi}{(\phi-\mu_H+vr)\xi}\right)^{\frac{1}{1-\xi}}\\
\iff\ &\frac{(1-\xi)(\phi-\mu_H)}{\xi vr} \leq \left(\frac{(\phi-\mu_H)\xi}{(\phi-\mu_H+vr)\xi}\right)^{\frac{1}{1-\xi}} + 1.
\end{aligned}$$

□

B.13 Proof of Corollary 6

Proof. First, absent commitment, the fee levied reads

$$f^* = \min\left\{\frac{(1-\xi)(vr+\phi)-\mu_H}{\xi(1-\alpha)} + \alpha\mu_H, \frac{vr}{\alpha} - \mu_H\right\},$$

which is—due to $vr \geq \mu_H$ —negative if and only if

$$\frac{(1-\xi)(vr+\phi)-\mu_H}{\xi(1-\alpha)} + \alpha\mu_H < 0,$$

i.e., if and only if

$$\mu_H > \mathcal{S} := \frac{(1-\xi)(vr+\phi)+\xi(1-\alpha)}{1-\xi(1-\alpha)}.$$

Second, with full commitment to a fee structure at time zero, Proposition 7 implies the optimal fee is given by

$$f^* = \min\left\{\frac{(1-\xi)\phi-\xi vr-\mu_H}{\xi(1-\alpha)} + \alpha\mu_H, \frac{vr}{\alpha} - \mu_H\right\},$$

which is smaller than zero if and only if

$$\frac{(1-\xi)\phi-\xi vr-\mu_H}{\xi(1-\alpha)} + \alpha\mu_H < 0,$$

i.e., if and only if

$$\mu_H > \mathcal{S} - \frac{vr}{1-\xi(1-\alpha)}.$$

□

B.14 Sketch of the Proof of Proposition 5

Proof. We heuristically derive the equilibrium. To account for users' preferences for a stable transaction medium, we stipulate that users evaluate payoffs with the stochastic discount factor:

$$\frac{d\Pi_t}{\Pi_t} = -rdt + (\pi_t - 1)dA_t \quad \text{with} \quad \Pi_0 = 1. \tag{43}$$

For simplicity, we impose the structure that $\pi_t = \pi \geq 1$, if $\varepsilon_t = \varepsilon_G$, and zero otherwise in that users are only risk-averse with respect to negative shocks $dA < 0$. The statement from the main text is obtained for $\pi = 1$.

Note that after time τ it suffices to characterize users' decision, as—by the assumption that π is sufficiently small—developers do not hold tokens anymore. Users solve the problem:

$$w_i := \max_{\{x_{it}\}} \mathbb{E}\left[\int_0^\infty \Pi_t dR_{it}\right] \quad \text{s.t.} \quad (43).$$

Note that users' utility flow is given by:

$$dR_{it} := \underbrace{A_t N_t^\chi \frac{x_{it}^\eta}{\eta} dt}_{\text{Convenience yield}} - \underbrace{x_{it}\phi\, dt}_{\text{Transaction cost}} + v x_{it}\Bigg(\underbrace{\frac{dP_t}{P_t}}_{\text{Capital gains}} + \underbrace{\frac{\alpha\, dD_t}{P_t}}_{\text{Dividend yield}} - \underbrace{r\, dt}_{\text{Funding cost}}\Bigg). \tag{44}$$

Under the appropriately defined risk-neutral measure $\tilde{\mathbb{P}}$, users attach a probability $\pi\rho dt$ instead of ρdt to a negative shock $dA_t < 0$, in case $\varepsilon_t = \varepsilon_B$. By the dynamic programming principle, users maximize:

$$\tilde{\mathbb{E}} dR_{it} = A_t N_t^\chi \frac{x_{it}^\eta}{\eta} dt - x_{it}(\phi + vr - \alpha\mu)dt + \pi\rho dt(P_B/P_G - 1)\mathbf{1}_{\{\varepsilon_t = \varepsilon_G\}} + \rho dt(P_G/P_B - 1)\mathbf{1}_{\{\varepsilon_t = \varepsilon_B\}}.$$

Going through the maximization yields

$$x_{it}^{1-\eta} = \frac{A_t P_t N_t^\chi dt}{\phi P_t dt + v\big(r P_t dt - \mathbb{E}[dP_t + \alpha\, dD_t]\big)},$$

in case utility features pin down the price and $N_i v = P_i \ \forall\ i \in \{G, B\}$. Utilizing that $x_{it} = N_t$ and the preceding discussion of returns and price dynamics, we obtain the equilibrium pricing system (of non-linear equations):

$$P_G = P_G(\alpha) = v\left(\frac{\bar{A} + \varepsilon_G}{vr - \alpha\mu(\bar{A} + \varepsilon_G) + \phi - \pi\rho(P_B/P_G - 1)}\right)^{\frac{1}{1-\xi}}$$

$$P_B = P_B(\alpha) = v\left(\frac{\bar{A} + \varepsilon_B}{vr - \alpha\mu(\bar{A} + \varepsilon_B) + \phi - \rho(P_G/P_B - 1)}\right)^{\frac{1}{1-\xi}}.$$

□

B.15 Proof of Corollary 7

Proof. Take $\bar{A} = A_H$. First, assume that utility features pin down the price in both states, in which case $\tilde{\mathbb{E}}(dP_t + \alpha dD_t) < rP_t dt \ \forall \ t \geq \tau$. Take the equilibrium pricing system

$$P_G = P_G(\alpha) = v\left(\frac{\bar{A}+\varepsilon_G}{vr - \alpha\mu(\bar{A}+\varepsilon_G) + \phi - \pi\rho(P_B/P_G - 1)}\right)^{\frac{1}{1-\xi}}$$
$$P_B = P_B(\alpha) = v\left(\frac{\bar{A}+\varepsilon_B}{vr - \alpha\mu(\bar{A}+\varepsilon_B) + \phi - \rho(P_G/P_B - 1)}\right)^{\frac{1}{1-\xi}},$$

and linearize it by means of a first-order Taylor expansion to

$$P_G = P_G(\alpha) = v\frac{\bar{A}+\varepsilon_G}{vr - \alpha\mu_H + \phi - \pi\rho(P_B/P_G - 1)} + o(\xi) + o(\max_A |\mu'(A)|)$$
$$P_B = P_B(\alpha) = v\frac{\bar{A}+\varepsilon_B}{vr - \alpha\mu_H + \phi - \rho(P_G/P_B - 1)} + o(\xi) + o(\max_A |\mu'(A)|).$$

The system can be solved for

$$P_G = \frac{v\ (A_H\,\phi + A_H\,\rho + \varepsilon_G\,\phi + \varepsilon_G\,\rho - A_H\,\alpha\,\mu_H + A_H\,r\,v + A_H\,\rho\,\pi - \alpha\,\varepsilon_G\,\mu_H + \varepsilon_G\,r\,v + \varepsilon_B\,\rho\,\pi)}{(\phi - \alpha\,\mu_H + r\,v)\ (\phi + \rho - \alpha\,\mu_H + r\,v + \rho\,\pi)}$$
$$+ o(\xi) + o(\max_A |\mu'(A)|)$$

and

$$P_B = \frac{v\ (A_H\,\phi + A_H\,\rho + \varepsilon_B\,\phi + \varepsilon_G\,\rho - A_H\,\alpha\,\mu_H + A_H\,r\,v + A_H\,\rho\,\pi - \alpha\,\varepsilon_B\,\mu_H + \varepsilon_B\,r\,v + \varepsilon_B\,\rho\,\pi)}{(\phi - \alpha\,\mu_H + r\,v)\ (\phi + \rho - \alpha\,\mu_H + r\,v + \rho\,\pi)}$$
$$+ o(\xi) + o(\max_A |\mu'(A)|).$$

One can then calculate that

$$\sigma = P_G - P_B = \sigma = \frac{v(\varepsilon_G - \varepsilon_B)}{\phi + \rho(1+\pi) + vr - \alpha\mu} + o(\xi) + o(\max_A |\mu'(A)|).$$

It is clear that σ is (approximately) increasing and convex in α for ξ and $\max_A |\mu'(A)|$ sufficiently small. The expressions in the Corollary are for $\pi = 1$.

Second, assume that security features pin down the price, in which case $\tilde{\mathbb{E}}(dP_t + \alpha dD_t) = rP_t dt \ \forall \ t \geq \tau$. In this case, the pricing system becomes Second, suppose that the token is held due to its dividend yields and/or capital gains it offers. Then:

$$P_G = P_G(\alpha) = \frac{\alpha\mu(\bar{A}+\varepsilon_G)N_G + \pi\rho P_B}{r+\rho} \quad \text{and} \quad P_B = P_B(\alpha) = \frac{\alpha\mu(\bar{A}+\varepsilon_B)N_B + \rho P_G}{r+\rho} \tag{45}$$

$$N_j = \left(\frac{\bar{A}+\varepsilon_j}{\phi}\right)^{\frac{1}{1-\xi}} \quad \text{for} \quad j = G, B, \tag{46}$$

which we can linearize as

$$P_G = P_G(\alpha) = \frac{\alpha\mu_H N_G + \pi\rho P_B}{r+\rho} + o(\max_A |\mu'(A)|)$$
$$P_B = P_B(\alpha) = \frac{\alpha\mu_H N_B + \rho P_G}{r+\rho} + o(\max_A |\mu'(A)|)$$
$$N_j = \left(\frac{\bar{A}+\varepsilon_j}{\phi}\right) + o(\xi) \quad \text{for} \quad j = G, B.$$

The system is solved by

$$\hat{P}_G = \frac{\alpha\,\mu_H\;(A_H\,r + A_H\,\rho + \varepsilon_G\,r + \varepsilon_G\,\rho + \pi\,\varepsilon_B\,\rho - \pi\,\varepsilon_G\,\rho)}{\varphi\;(r+\rho)\;(r+\rho-\pi\,\rho)} + o(\xi) + o(\max_A |\mu'(A)|)$$

and

$$\hat{P}_B = \frac{\alpha\,\mu_H\;(A_H + \varepsilon_B)}{\varphi\;(r+\rho-\pi\,\rho)} + o(\xi) + o(\max_A |\mu'(A)|).$$

One can then calculate that

$$\sigma = \frac{\alpha\mu(\varepsilon_G - \varepsilon_B)}{\pi(r+\rho)} + o(\xi) + o(\max_A |\mu'(A)|).$$

Clearly, σ is (approximately) linearly increasing in α for ξ and $\max_A |\mu'(A)|$ sufficiently small. The expressions in the Corollary are for $\pi = 1$. □

C Tokens vs. Equity Financing

This section studies in detail whether the the startup firm benefits from issuing both tokens and equity at time zero. The value of equity derives from the dividends received by shareholders. As a result, it is given by

$$E_{j,\tau} = \frac{(1-\alpha)N_j\mu_j}{r}$$

after time τ and by

$$E_j = \frac{\Lambda E_{j,\tau}}{r+\Lambda}$$

before time τ. We denote by γ developers' equity retention level after time zero. In our model, there is no reason to issue equity after time zero.

When the startup firm can issue equity at time 0, the financing constraint becomes

$$\frac{\Lambda}{r+\Lambda}\left((1-\beta)P_H + \frac{(1-\gamma)(1-\alpha)N_H\mu_H}{r}\right) = I, \tag{47}$$

as the startup firm can cover the cost I of developing the platform by raising equity and/or by selling tokens. Selling equity, like granting dividend rights to token holders, implies a dilution of the developers' stake in the firm. With equity financing, the incentive constraint becomes

$$\Lambda\left(\beta v + \frac{\gamma(1-\alpha)\mu_H}{r}\right)N_H - \kappa - \Lambda\left(\beta v + \frac{\gamma(1-\alpha)\mu_L}{r}\right)N_L \geq 0. \tag{48}$$

We can then derive developers' continuation payoff as

$$V_E(\alpha) = \frac{\Lambda(v\beta + \gamma(1-\alpha)\mu_H/r)N_H - \kappa}{r+\Lambda} = \frac{\Lambda S(\alpha) - \kappa}{r+\Lambda} - I,$$

where the subscript E denotes quantities under external equity financing, and formulate their optimization problem as

$$\max_{\alpha\in[0,1],\beta,\gamma} V_E(\alpha) \ \text{ s.t. (47)}.$$

Because equity is fairly priced, developers can extract all the surplus from the platform so that $V_E(\alpha)$ does not directly depend on (β, γ). Thus, for any α, developers choose (β, γ) to maximize $IC_E(\alpha)$. This leads to the following result.

Proposition 6. *Let α_{NE} denote the optimal level of security features without equity financing.*

1. *Equity financing $\gamma < 1$ is strictly suboptimal if $IC(\alpha_{NE}) = 0$ (i.e., $\alpha_{NE} < 1$) and $\mu_H > \mu_L$.*
2. *If $\mu_H = \mu_L$ or $IC(\alpha_{NE}) > 0$, equity financing yields the same payoffs as token-based financing.*

Proof. Take the financing constraint

$$(1-\beta)P_H + \frac{(1-\gamma)(1-\alpha)N_H\mu_H}{r} = \frac{(r+\Lambda)I}{\Lambda}$$

and implicitly differentiate wrt. γ to obtain

$$0 = -P_H\frac{d\beta}{d\gamma} - \frac{(1-\alpha)N_H\mu_H}{r} \Longrightarrow \frac{d\beta}{d\gamma} = -\frac{(1-\alpha)N_H\mu_H}{P_H r} = -\frac{(1-\alpha)\mu_H}{vr},$$

where we used the pricing relationship $P_H = N_H v$. We look at the incentive condition:

$$IC_E(\alpha) := \Lambda\left(\beta v + \frac{\gamma(1-\alpha)\mu_H}{r}\right)N_H - \kappa - \Lambda\left(\beta v - \frac{\gamma(1-\alpha)\mu_L}{r}\right)N_L \geq 0$$

and calculate:

$$\begin{aligned}\frac{dIC_E(\alpha)}{d\gamma} &\propto N_H\left(\frac{d\beta}{d\gamma} + \frac{(1-\alpha)\mu_H}{r}\right) - N_L\left(\frac{d\beta}{d\gamma} + \frac{(1-\alpha)\mu_L}{r}\right)\\ &= \frac{(1-\alpha)N_L}{r}(\mu_H - \mu_L) \propto \mu_H - \mu_L.\end{aligned}$$

Since $V_E(\alpha)$ does not directly on (β, γ), it follows that—given any value of α—optimal (β, γ) maximize $IC_E(\alpha)$.

As a consequence, whenever the incentive condition binds and $IC_E(\alpha') = 0$ for the optimal value α' under pure token-based financing $\gamma = 1$, then equity financing $\gamma < 1$ is strictly sub-optimal for $\mu_H > \mu_L$ and weakly sub-optimal if $\mu_H = \mu_L$. Lastly, note that the incentive condition binds, if κ, I or $1/\Lambda$ is sufficiently large. □

D The Problem before Time τ with Uncertainty after Time τ

Set $\bar{A} = A_H$. We assume that at time τ it follows that $\mathbb{P}(\varepsilon_\tau = \varepsilon_G) = 1/2$. The model solution from Section 3 upon replacing the token price P_H with the expected token price and expected adoption levels:

$$\bar{P} := \frac{P_G + P_B}{2} \quad \text{and} \quad \bar{N} := \frac{N_G + N_B}{2}.$$

Both $\bar{P}$ and $\bar{N}$ are increasing and convex in both A_H and α. Thus, the problem before time τ is barely changed by the introduction of productivity shocks after time τ.

E Micro-Foundation for Transaction Protocol and Holding Period

E.1 Microfoundation for Convenience Yield

The flow utility from transacting as stipulated in (1) can be micro-founded by a random search and matching protocol. For a detailed micro-foundation, we refer to Cong et al. (2019c,b).

E.2 Microfoundation for Token Holding Period

In the following, we give several potential ways to micro-found the holding period vdt. For the exposition, we consider our framework after the milestone, i.e., $t > \tau$, and assume that all users hold the tokens merely for transaction purposes. That is, the token is priced according to its utility features (which is the case if $vr > \alpha\mu_H$).

Transaction settlement delays. There are transaction settlement delays of length vdt. Consider a transaction that is initiated at time t. After the transaction is initiated, its execution is delayed by vdt units of time and so its execution is completed at time $t + vdt$. Notably, over $[t, t + vdt]$, tokens used in the transaction, initiated at time t, are locked and cannot be used otherwise, i.e., cannot be sold. After the transaction is executed at time $t + vdt$, tokens used in the transaction can be sold again. It follows that any transaction requires to hold tokens over a time period of length vdt.

In our model, the value of any transaction is one dollar, i.e., $1/P_t$ tokens. That is, N_t is the number of dollar transactions which are initiated over a short period of time $[t, t + dt)$. Thus, over any time period $[t, t + dt)$, N_t initiated transactions—each worth one dollar—require to hold $1/P_t$ tokens for vdt units of time.

Transactions are equally spread over time (i.e., over the time interval $[t, t + dt)$). This implies that at any time t, tokens are only held for transactions that are initiated over the interval $[t-vdt, t)$ (and so executed over $[t, t + vdt)$). The number of transactions initiated over $[t - vdt, t)$ equals

$$\frac{1}{dt}\left(\int_{t-vdt}^{t} N_s ds\right) = \frac{1}{dt}\left(\int_{t-vdt}^{t} (N_t + (N_s - N_t))\, ds\right) = \frac{1}{dt}\left(N_t vdt - o((dt)^2)\right) = vN_t, \tag{49}$$

where the second equality uses that $N_t - N_s \simeq dN_t$ is infinitesimal in that $ds(N_t - N_s) = o((dt)^2)$. The last inequality ignores higher order terms in that $o((dt)^2) = 0$.

As a result, at any time t, vN_t transactions, that have been initiated yet not executed, require to hold one dollar in tokens, i.e., $1/P_t$ dollars. Hence, the aggregate token demand equals vN_t/P_t, which by virtue of market clearing must equal the token market supply $1 - \beta_t$. Therefore, the token price equals:

$$P_t = \frac{vN_t}{1 - \beta_t}.$$

Deposits. Alternatively, we could obtain the same results by assuming that users have to hold fraction v of the overall transaction value in tokens over $[t, t+dt)$. Here, $v > 1$ implies that users have to put a deposit while $v < 1$ allows users to transact with margins. Specifically, a transaction of value x requires to holder vx tokens over $[t, t+dt)$. This implies the token demand vN_t/P_t and so—by virtue of market clearing—the token price:

$$P_t = \frac{vN_t}{1-\beta_t}.$$

F Full Commitment to Transaction Fees

Blockchain technology facilitates commitment to various metrics of platform and token design. For example, Cong et al. (2019b) demonstrate that the commitment to predetermined rules of token supply stimulates platform building. In this section, we analyze the effects of full commitment to future transaction fees. For simplicity, we conduct the analysis in the absence of agency frictions, i.e., assuming $\kappa = 0$.[13]

In line with economic intuition, Corollary 8 shows that developers charge lower transaction fees and that adoption is higher under full commitment.

Corollary 8. *Assume full commitment and $\phi > \mu_H$. Users incur the transaction fee:*

$$f^* = \min\left\{\frac{(1-\xi)\phi - \xi vr - \mu_H}{\xi(1-\alpha)} + \alpha\mu_H, \frac{vr}{\alpha} - \mu_H\right\}.$$

The fee increases in α for $\alpha \leq \alpha_2$ and decreases in α for $\alpha \geq \alpha_2$, where $\alpha_2 \in (0,1)$ is the unique solution to

$$\frac{(1-\xi)\phi - \xi vr - \mu_H}{\xi(1-\alpha)} + \alpha\mu_H = \frac{vr}{\alpha} - \mu_H \quad \text{if} \quad (1-\xi)\phi - \xi vr - \mu_H > 0,$$

and equals one otherwise. This implies the adoption level:

$$N_H^f = \begin{cases} \left(\frac{A_H\xi}{\phi-\mu_H}\right)^{\frac{1}{1-\xi}}, & \text{if } vr > \alpha(f+\mu_H) \iff \alpha \leq \alpha_2 \\ \left(\frac{A_H}{vr/\alpha+\phi-\mu_H}\right)^{\frac{1}{1-\xi}}, & \text{otherwise.} \end{cases}$$

Platform adoption and users' welfare is highest for $\alpha \geq \alpha_2$ if $\xi vr \geq (\phi - \mu_H)(1-\xi)$.

Remarkably, we find that the issuance of a utility token makes developers optimize platform adoption instead of cash flows under full commitment to transaction fees. It therefore follows that the ability to commit makes ICOs relatively more valuable.

Proposition 7. *Assume full commitment to fees $\{f\}$ and $\phi > \mu_H$. When the platform charges endogenous transaction fees, security features $\alpha \in [0, \alpha_2] \cup \{1\}$ are optimal. A value $\alpha \in [0, \alpha_2]$ yields the same profit as an ICO with $\alpha = 0$. A value $\alpha \leq \alpha_2$ is optimal if and only if:*

$$\frac{(1-\xi)(\phi-\mu_H)}{\xi vr} \leq \left(\frac{(\phi-\mu_H)\xi}{(\phi-\mu_H+vr)\xi}\right)^{\frac{1}{1-\xi}} + 1. \tag{50}$$

[13] Analyzing the fully-fledged agency problem requires to make additional assumptions about the fee structure in the off-equilibrium scenario $A = A_L$.

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