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# Optimal financing with tokens☆

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ABSTRACT

We develop a model in which a start-up firm issues tokens to finance a digital platform, which creates agency conflicts between platform developers and outsiders. We show that token financing is preferred to equity financing unless the platform expects strong cash flows, has large financing needs, or faces severe agency conflicts. Tokens are characterized by their utility features, facilitating transactions, and security features, granting cash flow rights. While security features trigger endogenous network effects and spur platform adoption, they also dilute developers' equity stake and incentives so that the optimal level of security features decreases with agency conflicts and financing needs.



## 1. Introduction

Initial coin offerings (ICOs) have become an important source of financing for firms that develop digital platforms (Howell et al., 2020). By the end of 2018, over 5500 firms had attempted to raise funds using an ICO, raising over 30 billion dollars (Lyandres et al., 2020) and with at least 20 ICOs taking in more than 100 million dollars (Howell et al., 2020). 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.

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

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Howey test as securities.[1] These tokens are called security tokens and are 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] Digital banking platforms—such as Nexo or Bankera—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 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 platform development and the ensuing agency conflicts between insiders (platform developers) and outsiders. Specifically, we develop a model in which a start-up firm, owned by penniless developers, builds a platform that facilitates peer-to-peer transactions among users. As in Cong, Li and Wang (2020b, 2021), 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, for example, from transaction fees, advertisement proceeds, and/or from using transaction data.

Entities conducting token offerings tend to have unproven business models and are most often in the preproduct stage (Howell et al., 2020). To capture these key features, we consider that the platform is initially not fully developed and the start-up firm has financing needs in that developers lack the funds to finance platform development. To raise the necessary funds, the start-up 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, platform success 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 start-up 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 start-up firm and undermine their incentives, which are determined by their equity ownership and by the tokens they retain. Crucially, equity and token incentives differ not only in their strength but also in their relation with the token design. This paper solves for the optimal token design in this environment characterized by financing needs and moral hazard and derives the following main findings.

First, considering the financing problem of a platform that uses tokens as a transaction medium, we demonstrate that issuing tokens to finance the start-up generally maximizes both developers' payoff and the value of the platform. We also show that while token security features trigger endogenous network effects and spur platform adoption, 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 start-up 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 underprovision 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 or the platform development phase is long, which induces low levels of security features and token retention.

Second, we analyze when it is optimal to issue a utility token without security features. That is, we analyze when developers prefer an ICO over an STO. 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 an STO 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 start-ups with innovative business models, which are particularly prone to moral hazard, optimally raise funds via ICOs, consistent with Fahlenbrach and Frattaroli (2020) or Howell, Niessner and Yermack (2020).

[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.

Third, we examine when it is optimal to use fiat money as the platform transaction medium and to issue equity to finance platform development. 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 (or security tokens that resemble conventional equity) may constrain developers' ability to raise funds and harm platform success, notably when platform value mostly comes from facilitating transactions among users. Financing platform development with equity is therefore only optimal if platform cash flows are expected to be large or if network effects are strong. For firms without very high cash flows (or very strong network effects), the platform is generally optimally financed with tokens, unless moral hazard is severe or financing needs are large.

Fourth, we study 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 should cause particularly volatile token prices.

Finally, we study various extensions of the model, in particular the relation between optimal platform financing and adverse selection. We demonstrate that adverse selection has ambiguous effects on the provision of token security features, depending on whether a separating or pooling equilibrium prevails. In a separating equilibrium, in which different types of platforms are financed with different types of tokens and ICOs and STOs coexist, adverse selection increases the provision of token security features by high-quality platforms, implying a positive relation between the provision of security features and the ex post value of platforms or the likelihood of platform success. In a pooling equilibrium in which all platforms are financed with the same tokens, adverse selection decreases the provision of token security features.

Our work is related to the literature on blockchain economics, tokenomics, and cryptocurrencies. Notable contributions include Athey et al. (2016), Abadi and Brunnermeier (2019), Makarov and Schoar (2020), Liu and Tsyvinski (2020), Cong and He (2019), Cao, Cong and Yang (2019), Huberman, Leshno and Moallemi (2020), Biais et al. (2019), Cong, He and Li (2020a), Prat and Walter (2019), Saleh (2020), Pagnotta (2020), Easley, O'Hara and Basu (2019), and Hinzen, John and Saleh (2020). 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 showing post-ICO patterns. Important contributions include Howell, Niessner and Yermack (2020), Fahlenbrach and Frattaroli (2020), and Lyandres, Palazzo and Rabetti (2020). 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, for example, Li and Mann (2020), Sockin and Xiong (2020), and Catalini and Gans (2018). Further theories on ICOs include Chod and Lyandres (2021), Chod, Trichakis and Yang (2019), Goldstein, Gupta and Sverchkov (2020), Holden and Malani (2019), Lee and Parlour (2019), Lyandres (2020), Malinova and Park (2017), and Mayer (2020). 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. Li and Mann (2021) provide a review of the early literature on ICOs.

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, Li and Wang (2021) analyze the pricing implications of users' intertemporal adoption decisions. Cong, Li and Wang (2020b) connect tokenomics to corporate finance, with a focus on optimal token-supply policy to finance investment in platform quality. While we employ similar modeling of users' platform adoption decisions, our paper differs from Cong, Li and Wang (2020b, 2021) in several important dimensions. First, Cong, Li and Wang (2020b, 2021) do not consider tokens with dividend rights and security features. Second, while Cong, Li and Wang (2020b) 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.

Finally, our paper also relates to the literature on the optimal design of securities. Seminal contributions include Townsend (1979), Gale and Hellwig (1985), and Bolton and Scharfstein (1990), or, in dynamic settings, DeMarzo and Sannikov (2006) and DeMarzo and Fishman (2007). Our focus is on the design of tokens and the comparison of tokens with equity financing. A distinguishing feature of our framework is that platform financing (i.e., the design of tokens) affects endogenous platform adoption, cash flows, and firm value, even if there are no frictions. By contrast, in standard models of security design, such a link between firm value and financing requires frictions (such as adverse selection, moral hazard, or taxes).

Section 2 presents the model. Section 3 solves for the optimal token design when the platform uses tokens as transaction medium. Section 4 analyzes the model implications. Section 5 derives conditions under which equity financing with fiat money as transaction medium is optimal. Section 6 examines the asset pricing implications of token utility and security features. Section 7 investigates the robustness of our findings to various model extensions. Section 8 summarizes our main testable predictions. Section 9 concludes. All proofs are 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 start-up firm that launches a digital platform but lack the capital to develop it. They obtain funds at time zero by issuing tokens, which serve as the transaction medium on the platform. They are in fixed unit supply and possess equilibrium price $P_t$. 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 equity financing when tokens serve as transaction medium. In particular, developers (optimally) do not issue outside equity and always own 100% of the start-up's equity.

*Platform transactions* The platform allows users to conduct peer-to-peer transactions. As in Cong, Li and Wang (2020b, 2021), 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 where $\eta \in (0, 1)$.[4] 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 $\nu dt$ units of time to transact.[5] Holding tokens is therefore costly because it implies a foregone opportunity to invest and earn interest for $\nu dt$ units of time. The parameter $\nu > 0$ 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 $\phi x_{it} dt$ 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, Li and Wang (2021).

*Cash flows*. Once developed, the platform generates cash flows

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

where $\mu(A_t)$ with $\frac{\partial \mu(A)}{\partial A} \geq 0$ 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 with the transaction volume $N_t$ and platform productivity $A_t$, as 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, for example, by setting (per-transaction) fees or selling user data. For analytical tractability, we assume that cash flows are linear in the transaction volume $N_t$ and there is no direct link between $\mu(A_t)$ and $\phi$ in that $\frac{\partial \mu(A)}{\partial \phi} = 0$. Under this assumption, the cost $\phi$ is a dead-weight loss as in, for example, Cong, Li and Wang (2021). Section 7 incorporates endogenous transaction fees charged by platform developers to users and analyzes their effects on token design and platform adoption and value.

*Platform development: moral hazard and financing.* Firms conducting token offerings are young and most often in the preproduct stage (Howell et al., 2020). To capture this feature, we consider that the platform is developed over some time period $[0, \tau)$ and is launched at time $\tau$ once a milestone has been reached. The arrival time of the milestone $\tau$ is governed by a Poisson process $M_t$ with constant intensity $\Lambda$ so that over each time interval of length $dt$ there is a probability $\Lambda dt$ 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 platform success depends on developers' hidden effort $a_t \in \{0, 1\}$, which comes against a flow cost $\kappa a_t$ to developers, with $\kappa \geq 0$.[7] 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

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

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 modeling of productivity shocks is also employed in, for example, Board and Meyer-ter Vehn (2013) and Hoffmann and Pfeil (2021). It follows that moral hazard is severe when the cost of effort $\kappa$ or the expected time to development $1/\Lambda$ is large. Define $\mu_j = \mu(A_j)$ for $j \in \{H, L\}$. Fig. 1 shows the timing of events over a time interval $[t, t + dt)$. For simplicity, platform productivity is constant after time $\tau$. We study the implications of productivity shocks arising after time $\tau$ in Section 6 and show that this assumption has no bearing on our key findings.

In addition to moral hazard, the start-up firm faces financing needs in that platform development requires in-

[4] This utility flow can be micro-founded by a random search and matching protocol; see Cong, Li and Wang (2020b, 2021).

[5] Appendix D provides a micro-foundation for this holding period. Cong, Li and Wang (2020b, 2021) assume that $\nu = 1$. When $\nu = 0$, security tokens have no transaction value and resemble conventional equity.

[6] Because, in practice, blockchain protocol and settlement latency (Easley et al., 2019; Hautsch et al., 2019) limit the influence that developers have on $\nu$, 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, ten minutes.

[7] Section 7 shows that this setup is isomorphic to a model with cash diversion. We thank the referee for encouraging us to generalize the model in this direction.

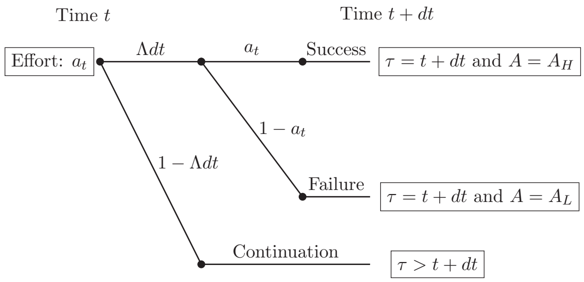


**Fig. 1.** Heuristic Timing over $[t, t+dt)$. With probability $\Lambda dt$, platform development is complete. Platform success depends on developers' hidden effort $a_t \in \{0, 1\}$.

vesting $I > 0$ 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. Funds raised by issuing tokens must be sufficient to cover the financing needs of the firm, leading to the constraint:

$$(1 - \beta_0)P_0 \geq I. \tag{3}$$

Funds raised at time zero are optimally invested in platform development or are paid out as dividends.

Developers have incentives to exert effort because they hold tokens and own the firm's equity. While providing the funds 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 $\tau$.[8] That is, developers sell $1 - \beta_0$ tokens at time zero and $\beta_0$ tokens at time $\tau$. We emphasize that we do not restrict developers to this particular token trading behavior. Because the only productivity shock realizes at time $\tau$ and developers and users discount at the same rate $r$, there is simply no reason to trade at any other time $t \notin \{0, \tau\}$. We therefore denote the developers' token holdings $\beta_t$ over $[0, \tau)$ by $\beta$.

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

In summary, token utility features are represented by the convenience yield in (1). Token security features are captured by the token dividends $\alpha dD_t$. In practice, the Howey test would classify any token with cash flow rights as security, so 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 ICOs 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 practices. In particular, tokens without cash flow rights (i.e., with $\alpha = 0$) are typically not classified as securities and are therefore referred to as utility tokens.

*Users' adoption decisions.* Before the platform is developed at time $\tau$, 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 investors the required return, $rP_t\, dt$:

$$\mathbb{E}[dP_t + \alpha\, dD_t] = rP_t\, dt \quad \text{for} \quad t < \tau. \tag{4}$$

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

$$dR_{it} := \underbrace{A_t N_t^{\chi} \frac{x_{it}^{\eta}}{\eta} dt}_{\text{Convenience yield}} - \underbrace{x_{it}\phi\, dt}_{\text{Transaction cost}} + \nu x_{it}\Bigg( \underbrace{\frac{dP_t}{P_t}}_{\text{Capital gains}} + \underbrace{\frac{\alpha\, dD_t}{P_t}}_{\text{Dividend yield}} - \underbrace{r\, dt}_{\text{Funding cost}} \Bigg). \tag{5}$$

Eq. (5) 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 $(\nu r + \phi)x_{it}$ that consists of the (funding) costs of holding tokens and the direct transaction costs.

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

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

This yields an optimal transaction volume given by

$$x_{it}^{1-\eta} = \frac{A_t P_t N_t^{\chi}\, dt}{\phi P_t dt + \nu\big(rP_t dt - \mathbb{E}[dP_t + \alpha\, dD_t]\big)}. \tag{6}$$

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

$$N_t = \left( \frac{A_t}{\nu r - \nu \mathbb{E}[dP_t + \alpha dD_t]/(P_t dt) + \phi} \right)^{\frac{1}{1-\xi}}, \tag{7}$$

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 $\beta_t$, and the cash flow rights $\alpha$ 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

$$V_0 = \max_{\alpha, \{\beta_t\}, \{a_t\}} \mathbb{E}\Big[ \int_0^{\infty} e^{-rt} (-P_t\, d\beta_t + (1 - \alpha + \alpha\beta_t) dD_t - \kappa a_t dt) \Big] - I, \tag{8}$$

subject to the financing constraint (3).

[8] Section 7 introduces speculators in the model and convex effort costs and shows that, in this alternative setup, developers may continuously trade between inception and the milestone. It also shows that this extension has no other bearings on our results. We thank the referee for encouraging us to generalize the model in this direction.

## 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
$$w_i := \max_{\{x_{it}\}} \mathbb{E}\left[\int_0^\infty, e^{-rt} dR_{it}\right], \tag{9}$$
and developers solve (8).
2. The token market clears before the milestone in that (4) is satisfied for all $t < \tau$.
3. The token market clears after the milestone in that
$$\frac{\nu}{P_t}\left(\int_0^1 x_{it} di\right) = \frac{\nu N_t}{P_t} \le 1 - \beta_t \tag{10}$$
for all $t \ge \tau$. If and only if the inequality (10) is strict, (4) holds for $t \ge \tau$.

The left-hand side in the market clearing condition (10) 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 $\nu$. Intuitively, if $\nu$ is large, users from previous transaction periods need to hold tokens in the current period, thereby increasing demand. (Appendix D 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 (4).

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, we then determine the optimal level of security features $\alpha$ and the optimal level of token retention $\beta$.

### 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 $\tau$, it follows that all quantities remain constant at levels $X_j = X_t$ for all $t \ge \tau$ for $X \in \{P, N\}$ in that $dP_t = 0$ for all $t \ge \tau$. We incorporate uncertainty after time $\tau$ in Section 6, 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 $\tau$. 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 $\tau$. Thus, developers sell all retained tokens at time $\tau$ so that $\beta_t = 0$ for all $t \ge \tau$. This implies that the value of developers' stake in the start-up firm at time $\tau$ is equal to the value $\frac{(1-\alpha)\mu_j N_j}{r}$ of the start-up'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 $rP_j$, 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 of length $\nu dt$ and the effective token demand over a short period of time $[t, t+dt)$ is then given by $\nu N_\tau/P_\tau$. Token supply for $t \ge \tau$ is given by $1 - \beta_t = 1$. Market clearing therefore implies that
$$P_j = \nu N_j.$$

Combining the two cases, we obtain that the user base in Eq. (7) simplifies to
$$N_t = N_j(\alpha) = N_j = \left(\frac{A_j}{\max\{0, \nu r - \alpha\mu_j\} + \phi}\right)^{\frac{1}{1-\xi}}, \tag{11}$$
and the token price is given by
$$P_t = P_j = \begin{cases} \nu\left(\frac{A_j}{\nu r - \alpha\mu_j + \phi}\right)^{\frac{1}{1-\xi}} & \text{if } \nu r > \alpha\mu_j \\ \frac{\alpha\mu_j}{r}\left(\frac{A_j}{\phi}\right)^{\frac{1}{1-\xi}} & \text{if } \nu r \le \alpha\mu_j. \end{cases} \tag{12}$$
Eqs. (11) and (12) reveal that utility features determine the token price if and only if the opportunity cost $\nu r$ of holding tokens exceed the token dividend yield $\alpha\mu_j$. Thus, in our framework, $\nu$ and $\alpha$ determine the users' underlying motive to hold tokens. When $\nu$ is relatively large compared to $\alpha$, users hold tokens over an extended time period mainly for transaction purposes and therefore because of their utility features. By contrast, if $\nu$ is low compared to $\alpha$—for instance, when fiat money can be used as transaction medium on the platform and $\nu = 0$—tokens are only held for their cash flow rights and their price increases with $\alpha$.

Last, the token price and platform adoption are closely related to the token velocity, defined as the ratio of the platform's real transaction value over the token market capitalization. In our model, it is given by
$$velocity := \frac{N_t}{P_t} = \min\left\{\frac{1}{\nu}, \frac{r}{\alpha\mu(A_t)}\right\}.$$
This equation shows that if the token is priced according to its utility features, token velocity equals the inverse of the holding period $\nu$. Remarkably, security features $\alpha > 0$ bound the token velocity from above and so can be useful to address problems associated with high token velocity.[9]

### 3.2. Model solution before the milestone

#### 3.2.1. Incentive compatibility

Consider first developers' incentives to maximize the platform's transaction value through their effort choice $a_t$.

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

Suppose developers exert effort so that $a_t = 1$. With probability $\Lambda dt$, the milestone arrives over the next time interval and future platform productivity equals $A_H$ so that developers' payoff at time $\tau$ equals

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

which is the sum of the value of the tokens they retain and the present value of future cash flows. By contrast, if developers shirk and choose $a_t = 0$, future platform productivity becomes $A_L$ and their payoff at time $\tau$ equals

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

Hence, developers exert effort at any time $t < \tau$ (i.e., $a_t = 1$) if and only if

$$IC(\alpha) := \underbrace{\Lambda\left(\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}\right) - \kappa}_{\text{Payoff under } a_t=1} - \underbrace{\Lambda\left(\beta P_L + \frac{(1-\alpha)\mu_L N_L}{r}\right)}_{\text{Payoff under } a_t=0} \geq 0. \tag{13}$$

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

### 3.2.2. Developers' problem and initial token issuance

Consider next the platform development phase $[0, \tau)$. Unless otherwise mentioned, we assume that platform development costs $I$ are not prohibitively large and full effort is optimal. In addition, we set $\mu_L = 0$ for analytical convenience, so that the platform produces cash flows if and only if developers exert effort. These assumptions are gathered in the following:

*Assumption 1*. Exerting effort is efficient in that the project produces cash flows and has positive net present value (NPV) if and only if $a_t = 1$ for all $t < \tau$. Formally, (A.1), (A.2), and (A.3) in Appendix A have to be met.

When Assumption 1 is satisfied and developers exert effort, 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

$$P_t = P_0 = \frac{\Lambda P_H}{r + \Lambda}. \tag{14}$$

Notably, absent further constraints, developers and users value tokens equally before time $\tau$ as they both apply the same discount rate. However, because a higher retention level $\beta$ relaxes condition (13), developers issue the minimal amount of tokens needed to finance platform development. We thus have for $\beta = \beta_0$:

$$(1-\beta)P_0 = I \iff \beta = 1 - \frac{I}{P_0}. \tag{15}$$

Developers optimally do not sell tokens over $(0, \tau)$ as there are simply no gains from trade so that $\beta_t = \beta$ for $t \in [0, \tau)$.

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

$$V(\alpha) = \frac{1}{r+\Lambda}\left[\Lambda\left(\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}\right) - \kappa\right] \tag{16}$$

with $\beta = 1 - \frac{I}{P_0}$. We can rewrite the value function as

$$V(\alpha) = \frac{\Lambda S(\alpha) - \kappa}{r + \Lambda} - I, \tag{17}$$

where

$$S(\alpha) = P_H + \frac{(1-\alpha)\mu_H N_H}{r}. \tag{18}$$

Eq. (17) is the NPV 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 value of all tokens in circulation and the value of the start-up equity after $\tau$. Therefore, $S(\alpha)$ captures the monetary platform value after time $\tau$, that is, the overall surplus in dollar terms. In Eq. (18), $P_H$ is the value of all tokens (i.e., the token market capitalization) 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 $\alpha$ to maximize the value they extract from the platform. That is, developers solve

$$\max_{\alpha \in [0,1]} V(\alpha) \quad \text{s.t.} \quad (13) \quad \text{and} \quad (3). \tag{19}$$

Using Eq. (17), we thus have that developers maximize $S(\alpha)$ subject to the incentive constraint (13) and the financing constraint (3). We conclude the section by establishing the existence of an equilibrium with positive adoption.[10]

*Proposition 1* (Equilibrium existence). *There exists a 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 function is given by (17) for $t < \tau$ and equals zero for $t \geq \tau$.*
2. *Developers sell tokens only at times 0 and $\tau$, and the retention level is given by (15) and $\beta_t = 0$, $\forall t \geq \tau$. The optimal level of security features $\alpha$ is characterized by (8).*
3. *The token price is characterized by (12) for $t \geq \tau$ and by (14) for $t < \tau$.*

## 4. Analysis

### 4.1. The frictionless benchmark

We start by studying the model without moral hazard. In this frictionless benchmark, the incentive compatibility constraint (13) becomes irrelevant, and developers choose $\alpha$ to maximize the platform value $S(\alpha)$. This holds true

[10] 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.

even if $I > 0$. The following proposition demonstrates that absent agency conflicts and transaction costs (i.e., for low $\phi$), full dividend rights $\alpha = 1$ are optimal when token are priced according to utility features (i.e., when $\nu r \geq \mu_H$). It also shows that an increase in transaction costs generally reduces the optimal amount of security features.

*Proposition 2* (Frictionless benchmark). *Define* $\hat{\alpha} = \min\left\{1, \frac{\nu r}{\mu_H}\right\}$. *When there is no moral hazard* ($\kappa = 0$), *developers maximize* $S(\alpha)$ *and choose* $\alpha = \bar{\alpha}$ *with* $\bar{\alpha} = \arg\max_\alpha S(\alpha)$, *satisfying*

$$\bar{\alpha} = \begin{cases} x \in [\hat{\alpha}, 1] & \text{if } \max\{\nu r - \mu_H, 0\} \geq \frac{(1-\xi)\phi - \mu_H}{\xi} \\ 0 & \text{if } \nu r \leq \frac{(1-\xi)\phi - \mu_H}{\xi} \\ \frac{\nu r}{\mu_H} + \frac{1}{\xi} - \frac{\phi(1-\xi)}{\xi \mu_H} & \text{otherwise.} \end{cases}$$

*When* $\bar{\alpha} \geq \hat{\alpha}$, *it holds that* $S'(\alpha) \geq 0$ *for* $\alpha \in [0, \hat{\alpha})$.

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 tokens are priced according to utility features and the cost of transacting on the platform is small and does not represent an impediment to platform development. Unlike $\alpha$, the parameter $\nu$ has ambiguous effects on platform adoption and token prices. An increase in $\nu$ raises the cost of transacting for users, hampering platform adoption in that $\frac{\partial N_H}{\partial \nu} < 0$. At the same time, an increase in $\nu$ may boost the token price due to the market clearing condition $P_H = \nu N_H$, which holds when tokens are priced according to utility features (i.e., when $\nu r \geq \mu_H$).

Throughout, we focus on environments in which the cost of transacting $\phi$ is low and the token is priced according to its utility features. That is, unless otherwise mentioned, we assume that

*Assumption 2.* Parameters satisfy

1. $\nu r > \mu_H$ and
2. $\nu r > \frac{(1-\xi)(\phi - \mu_H)}{\xi}$.

The first condition ensures that the token is priced according to its utility features (i.e., $P_H = \nu N_H$). The second condition implies that $\bar{\alpha} = 1$ (see Proposition 2). As we show below, all frictions drive the level of security features below $\bar{\alpha} = 1$, so this choice can be viewed as a normalization.

### 4.2. Moral hazard and financing needs

As shown by (19), developers maximize $S(\alpha)$ subject to the incentive constraint (13) and the financing constraint (3). Since $\bar{\alpha} = 1$, $S'(\alpha) \geq 0$ for all $\alpha \in [0, 1]$ (see Proposition 2 with $\bar{\alpha} = \hat{\alpha} = 1$), and (3) is optimally tight as in (15), developers choose the maximal value $\alpha$ that satisfies the incentive constraint (13). Therefore, the optimal level of security features $\alpha$ in the tokens issued by the start-up 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 $\alpha$ and the token retention level $\beta$ depend on moral hazard and financing needs. In the absence of financing needs, that is, when $I = 0$, developers retain all tokens and can therefore 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 $\alpha$, the value of developers' equity before time $\tau$ 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 $\tau$. Here, $N(A)$ is the level of platform adoption as a function of $A$ and $\mu(A)N(A)$ is the platform's cash flow (also written as function of $A$). This implies that the incentives (i.e., the sensitivity with respect to productivity $A$) generated by a dollar of equity ownership are equal to

$$\frac{dE/dA}{E} = \underbrace{\frac{d\mu/dA}{\mu}}_{\substack{\text{Cash flow} \\ \text{sensitivity}}} + \underbrace{\frac{dN/dA}{N}}_{\substack{\text{Sensitivity} \\ \text{to platform} \\ \text{adoption}}}, \tag{20}$$

whereas the incentives from a dollar token ownership—owing to $P = \nu N$—are equal to

$$\frac{dP/dA}{P} = \frac{dN/dA}{N}. \tag{21}$$

Eqs. (20) and (21) 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. Therefore, incentives optimally become more equity based and less token based if the cost of effort (i.e., $\kappa$), 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

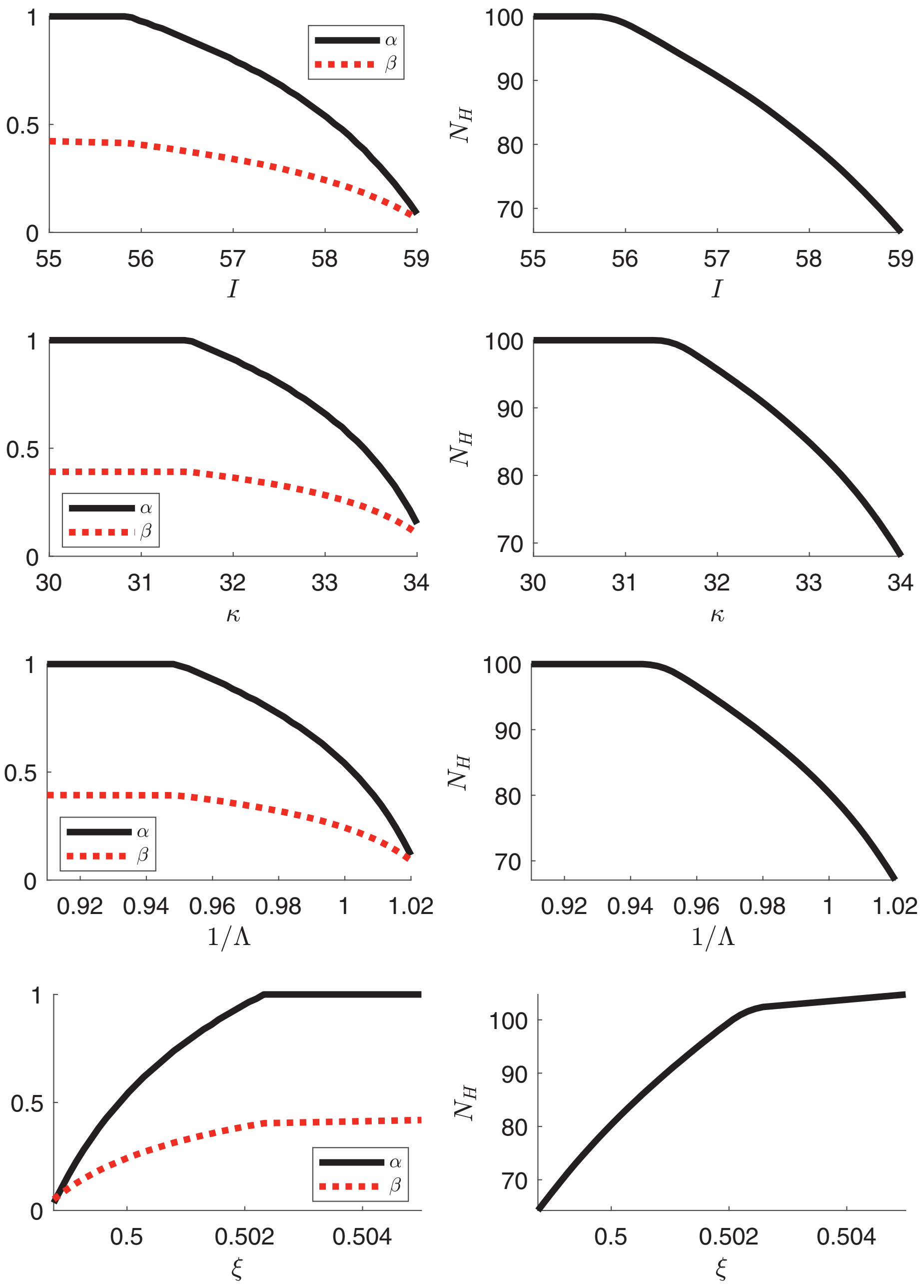


**Fig. 2.** The effects of financing needs $I$, moral hazard $\kappa$, expected time to platform development $1/\Lambda$, and network effects $\xi$ on token design and platform adoption.

an underprovision of token security features. The provision of equity incentives reduces the token price $P_H$ and thus requires developers to sell more tokens at inception to cover financing costs $I$, thereby reducing the token retention level $\beta$.

Fig. 2 illustrates these findings by plotting the optimal level of token security features $\alpha$ and developers' retention level $\beta$ as functions of financing needs $I$, the expected time to platform development $1/\Lambda$, and agency frictions $\kappa$. 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 (2020). The right panels of Fig. 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.

Remarkably, network effects $\xi$ relax the incentive condition (13). 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 as security features lead to higher cash flows to token holders and boost adoption, which triggers even higher cash flows and adoption. These endogenous network effects arising from the cash flow channel are amplified by the exogenous network effects $\xi$. As a result, stronger network effects imply more token-based incentives, that is, a higher retention level $\beta$, and less equity incentives $1-\alpha$ to developers as illustrated by Fig. 2.

Finally, we also demonstrate that it is strictly suboptimal for developers to raise funds by issuing equity next to (transaction) tokens. This is for two reasons. First, because equity incentives are stronger than token incentives, selling equity to outside investors exacerbates moral hazard, which is costly when either $\kappa, 1/\Lambda$, or $I$ is sufficiently large. Second, while the high cash flow rights $\alpha$ attached to tokens spur platform adoption, they also reduce the start-up firm's equity value and preclude a financing via equity. These two mechanisms make it optimal to bundle transaction benefits and cash flow rights in (i.e., attach utility and security features to) one security rather than offering two securities that deliver dividends and transaction benefits separately.

The following proposition gathers our analytical results.

*Proposition 3* (Optimal token financing). *The following holds:*

1. *Optimal token security features are given by $\alpha=\bar{\alpha}$ if either $\kappa$, $1/\Lambda$, or $I$ is sufficiently small.*
2. *The optimal level of security features satisfies $\frac{d\alpha}{dI} \leq 0$, $\frac{d\alpha}{d(1/\Lambda)} \leq 0$, and $\frac{d\alpha}{d\kappa} \leq 0$, where the inequalities are strict only if the incentive condition (13) is tight.*
3. *The optimal token retention level satisfies $\frac{d\beta}{dI} < 0$, $\frac{d\beta}{d(1/\Lambda)} > 0$, and $\frac{d\beta}{d\kappa} \leq 0$, where the latter inequality is strict only if the incentive condition (13) is tight.*
4. *If $A_H > \nu r + \phi$, then $\frac{\partial IC(\alpha)}{\partial \xi} > 0$ for any $\alpha \in [0,1]$, $\frac{d\alpha}{d\xi} \geq 0$, and $\frac{d\beta}{d\xi} > 0$. The former inequality is strictly only if the incentive condition (13) is tight.*
5. *Raising funds by issuing equity next to tokens is strictly suboptimal.*

### 4.3. ICO versus 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 ICO (see Howell et al., 2020; Fahlenbrach and Frattaroli, 2020). The following proposition establishes that whether an ICO is preferred to an STO depends on platform characteristics.

*Proposition 4* (ICOs versus STOs). *An ICO (i.e., $\alpha=0$) is optimal if $\mu_H \leq (1-\xi)\phi - \xi \nu r$. An STO (i.e., $\alpha>0$) is optimal if*

1. *$\mu_H > (1-\xi)\phi - \xi\nu r$ and*
2. *either $\kappa$, $1/\Lambda$, or $I$ is sufficiently small.*

The comparison between an ICO and STO can be conducted for a fixed platform value since the statements in Proposition 4 do not explicitly involve $A_H$. The inequality conditions in Proposition 4 imply that when the platform is expected to generate low (or even negative) cash flows (i.e., for low $\mu_H$), 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 STOs even though the issuance of a security token dilutes developers' cash flow rights. The economic mechanism behind this result is that granting cash flow rights to users spurs platform adoption, which is particularly valuable for large $\mu_H$. Proposition 4 also implies that stronger network effects (i.e., high $\xi$) favor STOs. This is because cash flow rights embedded in security tokens magnify network effects and spur platform adoption even more.

Proposition 4 also demonstrates that financing and agency frictions make STOs less attractive. This is because an increase in frictions renders equity incentives more valuable, thereby reducing the value of security tokens relative to utility tokens. Likewise, 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., 2020; Fahlenbrach and Frattaroli, 2020) report that many ICO financed projects have not yet delivered 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.

Fig. 3 illustrates these results. Our baseline parameter values are such that STOs dominate ICOs. Under severe financing and agency frictions, it may become optimal to issue a pure utility token via an ICO to avoid diluting developers' equity stake.

## 5. Equity versus tokens: when to include token utility features?

We have worked so far under the assumption that tokens serve as the platform transaction medium. Instead, platform developers can decide to use fiat money as a transaction medium. Doing so removes utility features from tokens. It also eliminates the token holding period $\nu dt$, thereby reducing users' effective transaction costs. When $\nu=0$, the adoption level and token price satisfy

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

which shows using fiat money as a transaction medium potentially spurs adoption and that 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 $\alpha$ becomes irrelevant. The overall sur-

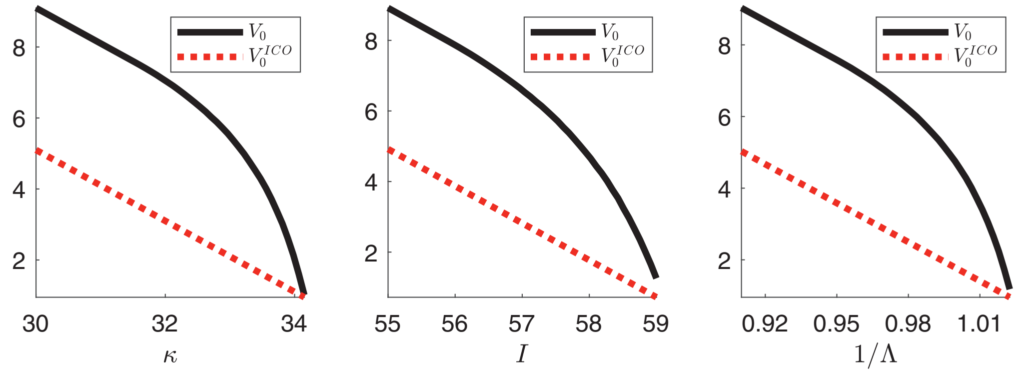


**Fig. 3.** ICO versus STO. $V_0$ and $V_0^{ICO}$ represent the developers value under the optimal security token ($\alpha > 0$) and utility token ($\alpha = 0$), respectively.

plus is then given by

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

which is just the platform expected dividend stream and is independent of the choice of $\alpha$. In the analysis below, we examine when equity financing (in combination with fiat money as a transaction medium) dominates token financing (in combination with tokens as a transaction medium).

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

$$V_0 = \max_{\alpha, \nu^* \in \{0,\nu\}, \{\beta_t\}, \{a_t\}} \mathbb{E}\left[\int_0^\infty e^{-rt}(-P_t\, d\beta_t + (1-\alpha+\alpha\beta_t)dD_t - \kappa a_t dt)\right] - I. \quad (22)$$

Proposition 5 derives conditions under which equity financing is optimal.

*Proposition 5* (Optimality of equity financing). *Issuing equity to finance platform development and using fiat money instead of tokens as platform transaction medium is optimal if and only if*

$$\frac{\mu_H}{\nu r} \geq \left(\frac{\phi}{\nu r - \mu_H + \phi}\right)^{\frac{1}{1-\xi}} \quad (23)$$

*and always leads to a higher level of adoption. Otherwise, a token-based platform is optimal. Condition (23) is satisfied if $\nu$ or $\xi$ are sufficiently large or if $\mu_H \in [\phi(1-\xi), \nu r)$ is sufficiently large. A token-based platform is optimal if*

1. *Condition (23) is not satisfied and*
2. *either $\kappa$, $1/\Lambda$, or $I$ is sufficiently small.*

Proposition 5 shows that token financing is optimal if network effects or platform cash flows are not very high. 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 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 start-up uses fiat money as a transaction medium and is financed with equity. If, in addition, network effects are strong, reducing transaction costs by allowing users to transact with fiat money boosts adoption. As expected, using fiat money as a transaction medium also becomes optimal if the cost $\nu$ of transacting with tokens is large.[11]

Issuing equity to finance platform development and using fiat money as a transaction medium rather than tokens with utility features can be optimal for firms with lower cash flows if financing needs are large and agency frictions are severe. To understand this finding, note that a fiat-based platform implies that developers' value fully stems from their equity ownership in the start-up firm. Hence, developers' incentives are equity based and therefore stronger, which is particularly valuable if financing needs are large and moral hazard is severe. In line with this reasoning, equity financing (or a token without utility features) is preferred for large values of $\kappa$, $1/\Lambda$, or $I$.

Fig. 4 illustrates these findings by plotting the optimal financing choice of the platform for different levels of cash flows and frictions. In both panels, the platform has negative NPV for combinations of parameter values below the solid black line, so it cannot be financed. In both panels equity financing is always preferred when cash flows are very high (area above the dashed red line). For firms without high cash flows, the platform is generally financed with tokens unless frictions (moral hazard $\kappa$ or financing needs $I$) are very high, in which case it is financed with equity (top right corner). As frictions decrease, financing with tokens becomes optimal. Financing with tokens can even be optimal for platforms that do not generate cash flows (or very low cash flows) if the value of the transactions conducted by users is sufficiently large (bottom left corner).

Finally, according to Proposition 3, it is not optimal to raise funds by issuing equity next to tokens when the latter are used as a transaction medium. According to Proposition 5, it can be optimal to issue equity instead of tokens to finance platform development and use fiat

[11] Blockchain-based tokens may offer some transaction benefits over fiat money. These could be related to security, privacy, or reliability. Remarkably, in our model, tokens can become optimal even under the assumption that cash carries strictly lower transaction costs.

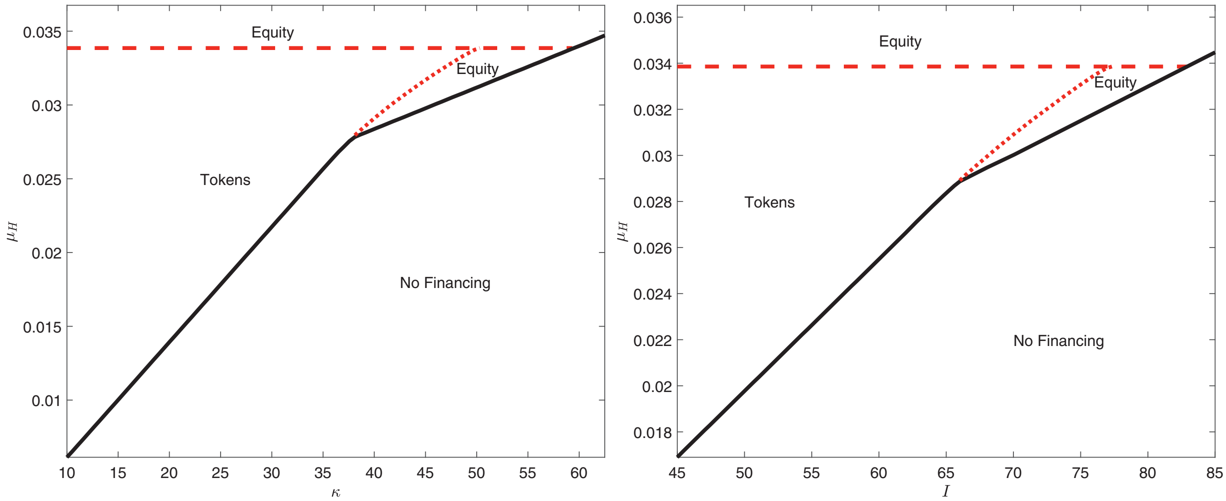


**Fig. 4.** Token financing versus equity financing. The figure plots the optimal financing strategy for platform developers for different combinations of cash flows $\mu_H$ and agency frictions $\kappa$ (left panel) or financing needs $I$ (right panel).

money as a platform transaction medium. As a result, financing with a mix of equity and tokens is not optimal, in that the start-up firm optimally finances platform development by issuing either tokens or equity.

## 6. Productivity shocks and token price volatility

We now allow for uncertainty after the milestone by introducing persistent productivity shocks that are not affected by developers' actions. Importantly, the introduction of productivity shocks after time $\tau$ does not qualitatively affect developers' decisions before time $\tau$, in that the results derived above continue to hold (see Appendix C.2). Our focus in this section is therefore on the asset pricing implications of token utility and security features rather than on developers' problem.

We introduce productivity shocks 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 shock $dA = \varepsilon_B - \varepsilon_G$ over $dt$ with probability $\rho dt$. Likewise, if $\varepsilon = \varepsilon_B$, the platform experiences a positive shock $dA = \varepsilon_G - \varepsilon_B$ with probability $\rho dt$. Consequently, the volatility of the productivity shocks, that is, fundamental volatility, is given by $\varepsilon_G - \varepsilon_B$. Fig. 5 depicts the structure of productivity shocks over $[t, t + dt)$. We emphasize that productivity shocks, unlike $\bar{A}$, are purely random and are 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 therefore volatility.

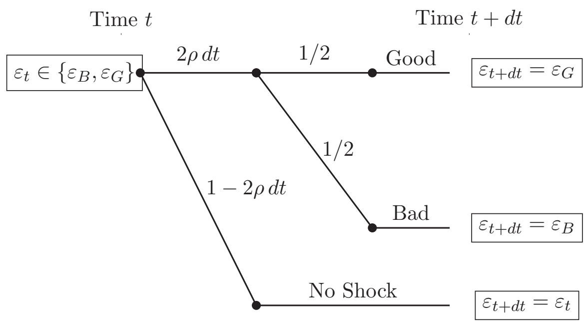


**Fig. 5.** Productivity shocks over $[t, t + dt)$. The branches of the tree contain the probabilities of the respective random event over $[t, t + dt)$.

### 6.1. Solution

We characterize the equilibrium token pricing after time $\tau$ for a given $A_t = \bar{A}$. Formally, we have to derive the state-dependent adoption levels $N_G$ and $N_B$ and token prices $P_G$ and $P_B$. With productivity shocks, the platform produces state-contingent cash flows $dD_i = \mu(\bar{A} + \varepsilon_i)N_i dt$ for $i = G, B$, with $\mu'(\cdot) \geq 0$. Using the same steps as above shows that adoption satisfies at time $t \geq \tau$:

$$N_t = N_i = \left( \frac{\bar{A} + \varepsilon_i}{\phi + \upsilon \max\{0, r - \mathbb{E}[dP_i + \alpha dD_i]/[P_i dt]\}} \right)^{\frac{1}{1-\xi}}, \quad \text{for } i = G, B. \tag{24}$$

Let us next solve for the token price. Assume first that utility features price the token in both states $i = G, B$ so that $P_i = \upsilon N_i$. This is the case when $\mathbb{E}[dP_i + \alpha dD_i] < rP_i dt$ in both states $i = G, B$, that is, when the expected returns to holding tokens are lower than $r$. Using Eq. (24) and $\mathbb{E}dP_G = \rho(P_B - P_G)dt$, $\mathbb{E}dP_B = \rho(P_G - P_B)dt$ as well as $dD_i =$

$\mu(\bar{A}+\varepsilon_i)N_i dt$, we can solve for

$$P_t = \begin{cases} P_G = \nu\left(\frac{\bar{A}+\varepsilon_G}{\phi+\nu r-\alpha\mu(\bar{A}+\varepsilon_G)-\nu\rho(P_B/P_G-1)}\right)^{\frac{1}{1-\xi}}, \text{ if } \varepsilon_t=\varepsilon_G, \\ P_B = \nu\left(\frac{\bar{A}+\varepsilon_B}{\phi+\nu r-\alpha\mu(\bar{A}+\varepsilon_B)-\nu\rho(P_G/P_B-1)}\right)^{\frac{1}{1-\xi}}, \text{ if } \varepsilon_t=\varepsilon_B. \end{cases} \tag{25}$$

Assume next that token security features pin down the token price in both states $G, B$. In this case, $\mathbb{E}[dP_i+\alpha dD_i] = rP_i dt$ for $i=G,B$ and we can use $N_i = \left(\frac{\bar{A}+\varepsilon_i}{\phi}\right)^{\frac{1}{1-\xi}}$ and $dD_i = \mu(\bar{A}+\varepsilon_i)N_i dt$ for $i=G,B$ to solve for the token price as

$$P_t = \begin{cases} P_G = \frac{1}{r+\rho}\left(\alpha\mu(\bar{A}+\varepsilon_G)\left(\frac{\bar{A}+\varepsilon_G}{\phi}\right)^{\frac{1}{1-\xi}}+\rho P_B\right), \text{ if } \varepsilon_t=\varepsilon_G, \\ P_B = \frac{1}{r+\rho}\left(\alpha\mu(\bar{A}+\varepsilon_B)\left(\frac{\bar{A}+\varepsilon_B}{\phi}\right)^{\frac{1}{1-\xi}}+\rho P_G\right), \text{ if } \varepsilon_t=\varepsilon_B. \end{cases} \tag{26}$$

In general, the token prices $P_G$ and $P_B$ are not available in closed form unless one considers the limit case $\max_A|\mu'(A)| \to 0$ and $\xi \to 0$; see Proposition 6 below.[12] For parsimony, we do not discuss the case in which the token is priced according to its utility features in one state and its security features in another state.

### 6.2. Token price volatility: the role of utility and security features

Our objective is to characterize the effects of utility and security features on token price volatility. In the following, we analyze token price volatility both in absolute terms, that is, $\sigma := P_G - P_B$, and scaled by the average (steady-state) token price $\overline{P} = \frac{P_H+P_L}{2}$, that is, $\bar{\sigma} := \frac{\sigma}{\overline{P}}$.[13]

First, consider that token utility features pin down the token price in that the token derives its price from the level of adoption and $N_t = \nu P_t$. For $\max_A|\mu'(A)| \to 0$ and $\xi \to 0$, we have that

$$\sigma \simeq \frac{\nu(\varepsilon_G-\varepsilon_B)}{\nu(r+2\rho)-\alpha\mu_H+\phi},$$
$$\bar{\sigma} \simeq \frac{2(\varepsilon_G-\varepsilon_B)(\nu r-\alpha\mu_H+\phi)}{(2A_H+\varepsilon_G+\varepsilon_B)(\nu(r+2\rho)-\alpha\mu_H+\phi)}.$$

Naturally, volatility increases with fundamental volatility $\varepsilon_G-\varepsilon_B$. More interestingly, security features $\alpha$ amplify rather than curb the volatility. The reason is that higher security features imply stronger 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. Due to the endogenous network effects, volatility $\sigma$ and scaled volatility $\bar{\sigma}$ are increasing and convex in $\alpha$. In sum, network effects induced by token security features spur adoption at the cost of an increased price volatility. While closed-form expressions for the token price volatility are only available for $\max_A|\mu'(A)| \to 0$ and $\xi \to 0$, Fig. 6 numerically shows that the above findings also hold for our baseline environment for which $\mu'(\cdot) > 0$ and $\xi > 0$.

Second, consider that the token is priced according to its security features in both states $G$ and $B$, which is the case when $\nu$ is sufficiently small. In this case, using (26), one can calculate that

$$\sigma = \frac{\alpha}{r+2\rho}\left(\mu(\bar{A}+\varepsilon_G)\left(\frac{\bar{A}+\varepsilon_G}{\phi}\right)^{\frac{1}{1-\xi}} - \mu(\bar{A}+\varepsilon_L)\left(\frac{\bar{A}+\varepsilon_L}{\phi}\right)^{\frac{1}{1-\xi}}\right),$$

$$\bar{\sigma} = \frac{2r}{r+2\rho}\left(\frac{\mu(\bar{A}+\varepsilon_G)\left(\frac{\bar{A}+\varepsilon_G}{\phi}\right)^{\frac{1}{1-\xi}} - \mu(\bar{A}+\varepsilon_L)\left(\frac{\bar{A}+\varepsilon_L}{\phi}\right)^{\frac{1}{1-\xi}}}{\mu(\bar{A}+\varepsilon_G)\left(\frac{\bar{A}+\varepsilon_G}{\phi}\right)^{\frac{1}{1-\xi}} + \mu(\bar{A}+\varepsilon_L)\left(\frac{\bar{A}+\varepsilon_L}{\phi}\right)^{\frac{1}{1-\xi}}}\right).$$

That is, when the token is priced according to its security features, token price volatility $\sigma$ is linear in $\alpha$ and is therefore less sensitive to the provision of security features, while scaled volatility $\bar{\sigma}$ is independent of $\alpha$. This holds also true for $\xi > 0$ and $\mu'(A) > 0$. The reason for this lower sensitivity is that dividends do not generate network effects if the token is priced according to its security features. Overall, our results highlight that the combination of token utility and security features leads to especially high token price volatility.

The following proposition summarizes our analytical results.

*Proposition 6* (Token price volatility). *The following holds:*

1. *Consider the limiting case,* $\max_A|\mu'(A)| \to 0$ *and* $\xi \to 0$. *If the token is priced according to its utility features in both states G and B, then* $\sigma$ *and* $\bar{\sigma}$ *are increasing and convex in* $\alpha$.
2. *If the token is priced according to its security features in both states G and B, then* $\sigma$ *is linearly increasing in* $\alpha$ *and* $\bar{\sigma}$ *is independent of* $\alpha$.

## 7. Model extensions

### 7.1. Cash diversion

Appendix E modifies our baseline model by considering that developers can secretly divert cash and receive per dollar diverted $\lambda \in [0,1]$ dollars (in this extension effort choice is thus replaced by diversion). As in the baseline model, platform cash flows are observable after time $\tau$, and there is no moral hazard problem once the milestone is reached. We show in this appendix that the incentive compatibility constraint ensuring that developers do not divert funds is similar to that of the baseline model. For $\lambda \equiv \frac{\kappa(r+\Lambda)}{I}$, this model variant is in fact isomorphic to the baseline model.

### 7.2. Adverse selection

Appendix F extends our baseline model to incorporate adverse selection. We consider in this appendix that

[12] 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 $N_t$.

[13] Note that by our specification of productivity shocks, the system spends, on average, equal time in both states so that the expected long-run price is just the equal-weighted average of $P_G$ and $P_B$.

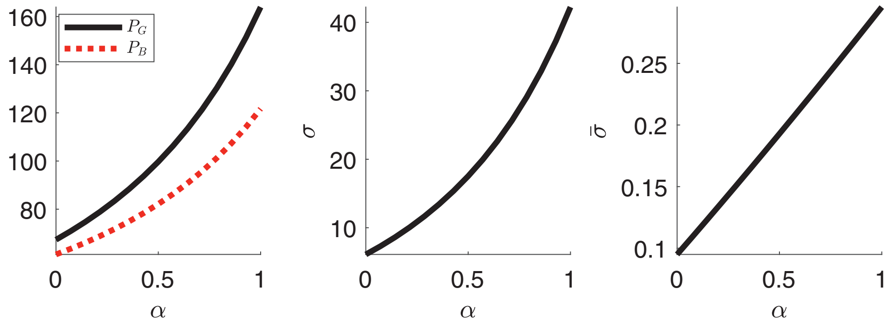


**Fig. 6.** Token price and volatility as functions of $\alpha$ in our base case environment with $\xi > 0$ and $\mu'(A) > 0$ and the baseline parameters. We pick $\mu(A) = \bar{\mu}A^{\omega}$, with $\bar{\mu} = 0.025$ and $\omega = 10$. $\bar{\sigma}$ is the volatility $\sigma$, divided by the steady-state token price $0.5(P_G + P_B)$. The shocks are characterized by $\varepsilon_G = -\varepsilon_B = 0.1$ and $\rho = 0.1$.

there exist two types of firms (platforms): a good platform, as described in the baseline version of the model, and a bad platform whose productivity after the milestone equals $A_t = A_L$ with $\mu_t = \mu_L$ with certainty. Both platforms require an initial investment of $I$. The platform is good with exogenous probability $\pi \in [0, 1]$. Developers are privately informed about platform quality. Token investors only know the probability $\pi$ that a platform is good. We demonstrate that because the bad type firm has negative NPV in the baseline model (under Assumption 1), there does not exist a separating equilibrium in our baseline environment where Assumption 1 is satisfied. The reason is that in a separating equilibrium, the bad type firm would not receive financing and thus would realize zero payoff, while mimicking the good type yields positive payoff.

Appendix F then studies the (unique) pooling equilibrium and shows that introducing adverse selection has no qualitative bearing on the model predictions regarding the effects of financing needs ($I$), cost of effort ($\kappa$), or expected time to platform development ($1/\Lambda$) on the optimal level of retention ($\beta$) and token security features ($\alpha$). The main effect of adverse selection is to quantitatively reduce the level of security features attached to tokens (of a good type platform). Indeed, in a pooling equilibrium, developers of a good type firm have to sell more tokens to cover initial financing needs due to the decrease in the token price relative to the perfect information case, leading to lower token retention $\beta$ and to greater moral hazard. To maintain incentive compatibility, developers must in turn possess more equity incentives, which requires granting lower cash flow rights to token holders.

To make the analysis complete, Appendix F relaxes Assumption 1 by considering environments in which bad type platforms have positive NPV. In this case, there may exist a separating equilibrium, in which token security features signal platform quality. Indeed, according to Proposition 2, attaching security features to tokens is only optimal if platform productivity and cash flows are sufficiently large. Thus, attaching security features to tokens is optimal for good type firms yet costly for bad type firms, facilitating a separating equilibrium. Such a separating equilibrium exists when financing needs ($I$) are sufficiently low, network effects ($\xi$) are large, transaction frictions ($\nu$) are high, or the platform cash flow rate is high. By contrast, sufficiently high costs of effort $\kappa$ or a sufficiently long time to project completion $1/\Lambda$ preclude the existence of the separating equilibrium.[14] That is, token security features signal good platform quality, but their ability to do so crucially depends on platform characteristics and the severity of moral hazard.

Moreover, in a separating equilibrium, adverse selection may boost the provision of token security features while increasing initial token retention by developers. The reason is that a good type firm signals platform quality by attaching more security features to tokens, thereby increasing the token price at time zero. Consequently, the developers of a good type firm sell fewer tokens to cover initial financing needs $I$.

In summary, the model implies that adverse selection has an ambiguous effects on the provision of token security features, depending on whether a separating or pooling equilibrium prevails. In a separating equilibrium, in which different types of platforms are financed with different types of tokens and ICOs and STOs coexist, adverse selection increases the provision of token security features. In a pooling equilibrium in which all platforms are financed with the same tokens, adverse selection decreases the provision of token security features.

### 7.3. Endogenous transaction fees

Appendix G extends the model by allowing developers to charge an endogenous fee $f > 0$ to users for transacting on the platform. This fee increases users' direct cost of transacting to $f + \phi$ and changes platform cash flows $(\mu(A_t) + f)N_t$ directly via $f$ and indirectly via $N_t$. We consider two cases depending on developers' ability to commit to a fee structure. In the main case discussed here, developers cannot commit.

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 $(\mu_H + f)N_H$. The optimal dynamic fee depends on whether the token utility or security features pin down the token price. Moreover, the op-

[14] When $\kappa$ or $1/\Lambda$ is large, exerting effort is no longer efficient and the good type prefers to mimic the bad type.

timal fee follows a hump-shaped pattern in $\alpha$. Thus optimal fees are the lowest when tokens have either minimum or maximum utility features with $\alpha = 0$ or $\alpha = 1$, respectively. This has a bearing on the optimal level of security features. As we show, the optimal tokens with endogenous transaction fees have either low or maximum security features, depending on some platform characteristics, but intermediate values of $\alpha$ are always suboptimal. In this context, the issuance of a utility token (i.e., $\alpha = 0$) or a token with heavy cash flow rights can be viewed as a commitment device not to charge high fees in the future, which is particularly useful in the presence of commitment problems to future fees.

Interestingly, the optimal transaction fee $f$ can be negative. In this case, the start-up firm subsidizes the user base to accelerate platform adoption. In practice, such subsidies are commonly employed by large technology firms. For instance, in 2019 Alibaba implemented a reward scheme providing subsidies to attract developers to its various platforms (Chod et al., 2019). Similarly, Uber is planning to offer financial services, including loans to drivers at favorable rates. We show in the appendix that subsidies to the user base are more likely if the platform is financed with utility tokens or if network effects $\xi$ are strong. In addition, subsidies are only optimal if the platform generates enough revenues $\mu_H$ to finance these subsidies. Finally, subsidies are more likely if the blockchain technology facilitates commitment, because with commitment, developers set fees with more focus on platform adoption instead of only on instantaneous cash flows.

### 7.4. Dynamic trading

Appendix H extends the model by considering the role of speculators. Because speculators are financially less constrained or more diversified than users and developers, their presence creates gains from trade, so developers benefit from selling tokens to speculators. As developers cannot commit their token trading strategy, trading opportunities can potentially undermine developers' incentives for platform development. To ensure smooth trading patterns, we introduce convex costs of effort for developers.

As in the baseline model, retained tokens $\beta$ provide incentives. However, the presence of gains from trade makes developers gradually sell their tokens throughout the development phase so that $\beta$ smoothly decreases. As developers cannot commit to keeping tokens, they sell tokens and decrease the token price up to the point that they become marginally indifferent between buying and selling them. Consequently, in equilibrium, all gains from trade are dissipated by the subsequent rise in agency costs. Appendix H shows how dynamic trading affects the amount of initial retained tokens $\beta$ and the rate of security features $\alpha$. We also demonstrate that the main predictions of the baseline model are robust to this extension.

### 7.5. Flow costs of platform development

Appendix I presents a model variant in which platform development requires operating (monetary) flow costs instead of an initial lump sum cost $I$ at time zero. To raise funds to cover these flow costs, developers dynamically sell tokens to the market, reducing their token retention level and incentives.[15] As a result, the model variant of Appendix I features similar forces at work and trade-offs as the model variant of Appendix H.

## 8. Predictions

Our paper provides several new empirical predictions related to platform financing and token design. In the following, we summarize our main predictions.

**Prediction 1:** *Using fiat money as the platform transaction medium and equity financing is only optimal for platforms that expect high cash flows or strong network effects. For firms without high cash flows and strong network effects (i.e., for which transaction benefits are more important as a source of platform value), using tokens as transaction medium and token financing is optimal unless moral hazard is severe or financing needs are large.*

This first prediction follows from Proposition 5 and relates to the optimal form of financing. According to this prediction, only platforms where expected cash flows are large (as a fraction of total platform value) should finance platform development with equity issues. Two additional key determinants of optimal financing are moral hazard, which is positively related to the expected time to platform completion, and the cost of developing the platform.

**Prediction 2:** *For firms relying on token financing, ICOs are expected to be more prevalent for platforms whose value comes mostly from facilitating transactions among users, while STOs are expected to be more prevalent for platforms whose value comes mostly from generating cash flows.*

This second prediction follows from Proposition 4 and shows that when using token financing the relative importance of cash flows versus transaction benefits is a key driver of token design.

**Prediction 3:** *For firms relying on token financing, token security features and developers' retention levels should decrease with the severity of moral hazard and the level of financing needs.*

The third prediction follows from Proposition 3 and underlines the importance of frictions in token design. Notably, because the incentives generated by each dollar of equity ownership are stronger than the incentives from a dollar of token ownership (and equity incentives are undermined by token security features), the level of security features in tokens should decrease with financing needs and moral hazard.

**Prediction 4:** *When different types of platforms are financed with different types of tokens and ICOs and STOs coexist, adverse selection increases the provision of token security features and the likelihood of platform success increases with token security features.*

The fourth prediction follows the analysis of the effects of adverse selection on token design. Our model predicts

[15] We assume in this appendix that there are no exogenous costs of selling tokens and raising funds. Introducing fixed costs of raising funds (similar to those in, e.g., Bolton et al., 2011; Hugonnier et al., 2015) would lead firms to retain cash and would add an additional state variable to the dynamic optimization problem of platform developers.

that in environments characterized by more informational asymmetries, for example, with less developed white papers or without code development on open source platforms, token security features should be more prevalent. It also predicts a positive relation between the ex post value of platforms or the likelihood of platform success and the level of token security features.

**Prediction 5:** *Token price volatility is increasing in security features.*

This last prediction follows from Proposition 6 and derives from the fact that security features generate endogenous network effects that increase the sensitivity of platform adoption to productivity shocks, thereby increasing volatility.

## 9. 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 start-up firms.

We show that dividend rights granted to token holders spur platform adoption but dilute developers' equity stake and therefore undermine 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, an STO or an ICO always dominates traditional equity financing when tokens serve as the transaction medium on the platform. By contrast, whether an STO is preferred to an ICO crucially depends on platform and start-up characteristics, notably the ability to generate cash flows in addition to facilitating transactions among users.

We also examine when it is optimal to use fiat money as the platform transaction medium and to issue equity to finance platform development. We find that financing platform development with equity is only optimal if platform cash flows are expected to be large or if network effects are strong. For firms without very high cash flows (or very strong network effects), the platform is generally optimally financed with tokens unless moral hazard is severe (due, e.g., to a long development phase) or financing needs are large.

Finally, we derive additional results by studying various extensions of the model. For instance, we consider the relation between optimal platform financing and platform transaction fees or adverse selection. Notably, we show that the issuance of a pure utility token can be viewed as a commitment device not to charge high transaction fees in the future. In addition, in environments characterized by informational asymmetries, token security features may signal good platform quality and thus may help to distinguish good token offerings from bad ones.

## Appendix A. Discussion of parametric assumptions

### A.1. Parameter conditions for the analytical solution

We give explicit parameter conditions for Assumption 1, which hold throughout unless otherwise mentioned.

1. We assume that platform development costs $I$ are not excessive and developers can raise $I$ dollars by issuing tokens, in that
$$I < v\left(\frac{\Lambda}{r+\Lambda}\right)\left(\frac{A_H}{vr+\phi}\right)^{\frac{1}{1-\xi}}. \tag{A.1}$$
Condition (A.1) ensures that (15) admits a positive solution, $\beta_0 > 0$, and thus facilitates financing.
2. We assume the project has NPV when full effort is exerted and token security features are chosen optimally, in that there exists $\alpha \in [0,1]$ with
$$\Lambda\left(P_H + \frac{(1-\alpha)\mu_H N_H}{r}\right) > (r+\Lambda)I + \kappa. \tag{A.2}$$
3. We assume that the project has negative NPV when no effort is exerted, in that
$$\Lambda\left(P_L + \frac{(1-\alpha)\mu_L N_L}{r}\right) \leq (r+\Lambda)I \tag{A.3}$$
for any $\alpha \in [0,1]$.

Note that conditions (A.2) and (A.3) jointly imply that $\Lambda\left(P_H + \frac{(1-\alpha)\mu_H N_H}{r} - P_L - \frac{(1-\alpha)\mu_L N_L}{r}\right) > \kappa$ for some $\alpha$, meaning that exerting effort is efficient. Also recall that $\mu_L = 0$.

### A.2. Parameters for the numerical analysis

As in Cong, Li and Wang (2020b), we set the discount rate to $r = 0.05$, the velocity parameters to $v = 1$, and the network effects parameter to $\chi = 0.125$. The parameter $\eta$ 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 (because the average time to milestone equals $1/\Lambda$). This is consistent with the findings of Fahlenbrach and Frattaroli (2020), 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 relation with $A_L$ matters. The value $A_L$ is set to $A_L = 0.55$.

The function $\mu(A)$ is such that $\mu_L = \mu(A_L) = 0$ and $\mu_H = \mu(A_H) = 0.025$, ensuring that $\mu_H < vr$ as stipulated by Assumption 1. 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 $I$ to match the 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 (2020). The effort cost $\kappa$ 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., 2020; Fahlenbrach and Frattaroli, 2020).

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

## Appendix B. Proofs for the baseline model

### B.1. Auxiliary results

We state the following two auxiliary lemmata.

*Lemma 1. Define $\hat{\alpha} = \min\{1, \frac{\nu r}{\mu_H}\}$. It holds that*

$$\bar{\alpha} = \arg\max_{\alpha} S(\alpha) = \begin{cases} x \in [\hat{\alpha}, 1] & \text{if } \max\{\nu r - \mu_H, 0\} \geq \frac{(1-\xi)\phi - \mu_H}{\xi} \\ 0 & \text{if } \nu r \leq \frac{(1-\xi)\phi-\mu_H}{\xi} \\ \frac{\nu r}{\mu_H} + \frac{1}{\xi} - \frac{\phi(1-\xi)}{\xi \mu_H} & \text{otherwise.} \end{cases}$$

*with* $S(\alpha) = P_H + \frac{(1-\alpha)\mu_H N_H}{r}$ *and* $N_H = \left(\frac{A_H}{\nu r - \alpha\mu_H + \phi}\right)^{\frac{1}{1-\xi}}$.
*When $\bar{\alpha} \geq \hat{\alpha}$, $S'(\alpha) > 0$ for $\alpha \in [0, \hat{\alpha})$.*

*Proof.* Recall that $\hat{\alpha} = \min\{1, \frac{\nu r}{\mu_H}\}$ and $N_H = \left(\frac{A_H}{\max\{0, \nu r - \alpha\mu_H\} + \phi}\right)^{\frac{1}{1-\xi}}$. First, note that for all $\alpha \in (\hat{\alpha}, 1]$, we have by (12) that $P_H = \frac{\alpha \mu_H N_H}{r}$, and thus $S(\alpha) = \frac{\mu_H N_H}{r}$ with $N_H = \left(\frac{A_H}{\phi}\right)^{\frac{1}{1-\xi}}$. Hence, $S(\alpha)$ does not depend on $\alpha$ for $\alpha > \hat{\alpha}$ (i.e., $S'(\alpha) = 0$ for $\alpha > \hat{\alpha}$).

Second, define $\varepsilon := 1/(1-\xi) \geq 1$, and calculate for $\alpha < \hat{\alpha}$ (in which case $P_H = \nu N_H$):

$$\begin{aligned} S'(\alpha) &= \varepsilon\left(\nu + \frac{(1-\alpha)\mu_H}{r}\right) N_H \frac{\mu_H}{\nu r - \mu_H \alpha + \phi} - \frac{\mu_H}{r} N_H \\ &\propto \varepsilon(\nu r + (1-\alpha)\mu_H)\frac{\mu_H}{\nu r - \mu_H\alpha + \phi} \\ &\quad - \mu_H \propto \varepsilon \nu r + \varepsilon(1-\alpha)\mu_H - \nu r + \mu_H\alpha - \phi \\ &= \nu(\varepsilon - 1)r + \varepsilon\mu_H - \alpha(\varepsilon-1)\mu_H - \phi \propto \nu r \\ &\quad + \frac{\mu_H}{\xi} - \alpha\mu_H - \frac{(1-\xi)\phi}{\xi}. \end{aligned}$$

It follows that $S'(\alpha)$ has at most one root on $(0, \hat{\alpha})$. If $\alpha = \bar{\alpha} \in (0, \hat{\alpha})$, then the optimal $\alpha = \bar{\alpha}$ solves the first order condition $S'(\bar{\alpha}) = 0$, so $\bar{\alpha} = \frac{\nu r}{\mu_H} + \frac{1}{\xi} - \frac{\phi(1-\xi)}{\xi\mu_H}$.

Next, if $S'(0) \leq 0$, then $S'(\alpha) < 0$ for all $\alpha < 0$; hence $\alpha = \bar{\alpha} = 0$ is optimal if $S'(0) \leq 0$. Observe that

$$S'(0) \leq 0 \Longleftrightarrow \frac{\nu r}{\mu_H} + \frac{1}{\xi} - \frac{(1-\xi)\phi}{\xi\mu_H} \leq 0.$$

The above inequality condition is equivalent to $\nu r \leq \frac{(1-\xi)\phi - \mu_H}{\xi}$.

Last, if $S'(\hat{\alpha}) \geq 0$, then $S'(\alpha) > 0$ for all $\alpha < \hat{\alpha}$, so $\alpha = \bar{\alpha} \in [\hat{\alpha}, 1]$ is optimal. Observe that

$$S'(\hat{\alpha}) \geq 0 \Longleftrightarrow \nu r - \hat{\alpha}\mu_H + \frac{\mu_H}{\xi} - \frac{(1-\xi)\phi}{\xi} \geq 0. \tag{B.1}$$

The above inequality can be compactly rewritten as $\max\{\nu r - \mu_H, 0\} \geq \frac{(1-\xi)\phi - \mu_H}{\xi}$. □

*Lemma 2. It holds that*

$$\arg\max_{\alpha} S(\alpha) = \arg\max_{\alpha}\left(\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}\right) - \frac{\kappa}{\Lambda},$$

*with* $S(\alpha) = P_H + \frac{(1-\alpha)\mu_H N_H}{r}$, $N_H = \left(\frac{A_H}{\max\{0, \nu r - \alpha\mu_H\} + \phi}\right)^{\frac{1}{1-\xi}}$, *and* $\beta = \beta_0$ *satisfying (15).*

*Proof.* Because $\beta = \beta_0$ satisfies (15), it holds that $\beta = 1 - \frac{I}{P_H}\frac{r+\Lambda}{\Lambda}$, implying

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

Because $\frac{\kappa}{\Lambda}$ and $\frac{(r+\Lambda)I}{\Lambda}$ do not depend on $\alpha$, the claim follows. □

### B.2. Proof of proposition 1

*Proof.* The assertion follows directly from the developments in the main text. □

### B.3. Proof of proposition 2

*Proof.* Lemma 1 derives the expression of $\bar{\alpha} = \arg\max_{\alpha \in [0,1]} S(\alpha)$. When $\kappa = 0$, there is no moral hazard problem and the incentive condition (13) (i.e., $IC(\alpha) \geq 0$) is not relevant for the developers' optimization problem (8). As a result, the developers solve $\max_\alpha \left(\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}\right) - \frac{\kappa}{\Lambda}$, where $\beta = \beta_0$ satisfies (15). By Lemma 2, the developers choose the level of $\alpha$ to maximize $S(\alpha)$ so that $\alpha = \bar{\alpha}$. □

### B.4. Proof of Proposition 3

#### B.4.1. Claim 1

*Proof.* When $\kappa/\Lambda \to 0$, the incentive condition $IC(\alpha) \geq 0$ is always satisfied for any $\alpha$ and is thus not relevant for the developers' optimization problem. As a result, the developers solve $\max_\alpha \left(\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}\right) - \frac{\kappa}{\Lambda}$, where $\beta = \beta_0$ satisfies (15). By Lemma 2, the developers choose the level of $\alpha$ to maximize $S(\alpha)$, so that $\alpha = \bar{\alpha}$. By continuity, it holds that $\alpha = \bar{\alpha}$ for sufficiently small $\kappa/\Lambda$, that is, for sufficiently small $\kappa$ or $1/\Lambda$.

Consider the limit case $I \to 0$, denoted by $I = 0$. When $I = 0$, the incentive condition $IC(\alpha) \geq 0$ becomes

$$\Lambda\left(P_H + \frac{(1-\alpha)\mu_H N_H}{r} - P_L\right) = \Lambda(S(\alpha) - P_L) \geq \kappa.$$

As by Assumption 2, $\alpha = \bar{\alpha} = 1$ maximizes $S(\alpha)$; it follows by means of parameter condition (A.2) (i.e., Assumption 1) that $\Lambda S(1) > (r+\Lambda)I+\kappa$. At the same time, parameter condition (A.3) implies that $P_L \leq (r+\Lambda)I$ for any $\alpha \in [0,1]$. As a result, $IC(\alpha) > 0$ for $\alpha = 1$. Because $\alpha = \bar{\alpha} = 1$ is the developers' optimal choice absent frictions (see Proposition 2 and Lemma 1), it follows that the incentive condition $IC(\alpha)$ is not relevant for the developers' optimization problem and is loose in optimum, when $I = 0$. That is, when $I = 0$, the developers maximize $S(\alpha)$ over $\alpha$ and choose $\alpha = \bar{\alpha} = 1$. By continuity, it follows that $\alpha = \bar{\alpha}$, provided $I > 0$ is sufficiently small. □

### B.4.2. Claims 2 and 3

*Proof.* Take the financing constraint (3) (which binds in optimum) or equivalently (15); that is, $\beta = 1 - \frac{I}{P_H}\frac{r+\Lambda}{\Lambda}$. It follows that $\beta$ strictly decreases in $I$ when $P_H$ decreases in $I$. Note that by the token pricing Eq. (12), $P_H$ does not depend on $I$ directly but only through the optimal choice of $\alpha$. Therefore, if $\beta$ increases in $I$, then $\alpha$ must strictly increase in $I$ because $P_H$ strictly increases in $\alpha$.

Take the surplus (i.e., overall platform value) $S(\alpha)$ and observe that $S(\alpha)$ does not depend on $I$ directly but only through the optimal choice of $\alpha$. Also note that an increase in financing frictions/needs, as captured by $I$, in optimum cannot cause more efficient provision of token security features $\alpha$, that is, cannot increase surplus $S(\alpha)$. Because $\alpha = \bar{\alpha} = 1$ is efficient and optimal absent frictions and when $I = 0$ and because $S'(\alpha) > 0$ for all $\alpha \in [0,1)$, this means that $\alpha$ cannot strictly increase in $I$. That is, $\alpha$ decreases in $I$ and so does $P_H$, implying that $\beta$ strictly decreases in $I$.

Also note that only if the incentive condition $IC(\alpha) \geq 0$ is tight, then $\alpha$ strictly decreases in $I$, as $I$ can affect the choice of optimal $\alpha$ only via the incentive condition (13). Analogously, it follows that $\beta$ strictly increases in $\Lambda$ and $\alpha$ (strictly) increases in $\Lambda$ (only if the incentive condition $IC(\alpha) \geq 0$ is tight).

Finally, note that $\kappa$ affects $P_H$ and thus $\beta$ only through the optimal choice of $\alpha$. If $P_H$ increases in $\kappa$, then $\alpha$ must increase in $\kappa$, as $P_H$ increases in $\alpha$. However, it is clear that an increase in agency frictions, as captured by $\kappa$, in optimum cannot trigger more efficient efficient provision of token security features $\alpha$, that is, cannot increase $S(\alpha)$. Because $\alpha = \bar{\alpha} = 1$ is efficient and optimal absent agency frictions (i.e., when $\kappa = 0$) and because $S'(\alpha) > 0$ for $\alpha \in [0,1)$, optimal $\alpha$ must decrease in $\kappa$. Thus, $d\beta/d\kappa \leq 0$ and $d\alpha/d\kappa \leq 0$, where the inequalities are strict only if the incentive condition $IC(\alpha) \geq 0$ is tight. □

### B.4.3. Claim 4

*Proof.* Note that $N_H = \left(\frac{A_H}{\upsilon r+\phi-\alpha\mu_H}\right)^{\frac{1}{1-\xi}} \geq \left(\frac{A_H}{\upsilon r+\phi}\right)^{\frac{1}{1-\xi}} > 1$, where the second inequality uses the parameter assumption $A_H > \upsilon r+\phi$. In addition, due to $N_H > 1$, it follows that $N_H$ strictly increases in $\xi$ and so does $P_H = \upsilon N_H$, thus $\frac{\partial\beta}{\partial\xi} > 0$ by means of (15) with $\beta = \beta_0$. Next, note that

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

Taking $IC(\alpha) = \Lambda\left(\beta\upsilon + \frac{(1-\alpha)\mu_H}{r}\right)N_H - \kappa - \Lambda\beta\upsilon N_L$, it follows that

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

where the first inequality uses $\mu_H > 0$ and the second inequality uses (B.2). Because $\alpha = \bar{\alpha} = 1$ is efficient absent frictions, because $S'(\alpha) > 0$ for all $\alpha \in [0,1)$, and because an increase in $\xi$ relaxes incentive compatibility (i.e., $\frac{\partial IC(\alpha)}{\partial\xi} > 0$), it follows that $\alpha$ increases in $\xi$ and $\beta$ strictly increases in $\xi$. Note that $\alpha$ strictly increases in $\xi$ only if the incentive condition $IC(\alpha) \geq 0$ is tight in optimum. □

### B.4.4. Claim 5

*Proof.* We show that developers do not find it optimal to issue equity next to tokens and start with some additional notation that allows for equity issuance (next to tokens). The value of equity derives from the dividends received by shareholders. As a result, it is given by the discounted stream of expected future dividends

$$E_{j,\tau} = \int_t^\infty e^{-r(s-t)}\mu(A_s)N_s(1-\alpha)ds = \frac{(1-\alpha)N_j\mu_j}{r}$$

after time $\tau$ (i.e., for $t \geq \tau$) for $j = H, L$ and by

$$E_j = \mathbb{E}_t\left[\int_t^\infty e^{-r(s-t)}\mu(A_s)N_s(1-\alpha)ds\right] = \frac{\Lambda E_{j,\tau}}{r+\Lambda}$$

before time $\tau$ (i.e., for $t < \tau$) for $j = H, L$. We denote by $\gamma$ the developers' equity retention level after time zero. In our model, there is no reason to issue equity after time zero. Further, it suffices to focus on instances in which $\alpha < 1$, as otherwise the equity value trivially equals zero.

When the start-up firm can issue equity at time 0, the financing constraint (which binds in optimum) becomes

$$\frac{\Lambda}{r+\Lambda}\left((1-\beta)P_H + \frac{(1-\gamma)(1-\alpha)N_H\mu_H}{r}\right) = I, \tag{B.3}$$

as the start-up 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

$$IC_E(\alpha) := \Lambda\left(\beta P_H + \frac{\gamma(1-\alpha)\mu_H N_H}{r}\right) - \kappa - \Lambda\beta P_L \geq 0. \tag{B.4}$$

We can then derive developers' (continuation) payoff before time $\tau$ as

$$\begin{aligned}V_E(\alpha) &= \frac{\Lambda(\upsilon\beta + \gamma(1-\alpha)\mu_H/r)N_H - \kappa}{r+\Lambda} \\ &= \frac{\Lambda S(\alpha) - \kappa}{r+\Lambda} - I,\end{aligned} \tag{B.5}$$

where the subscript "$E$" denotes quantities under external equity financing. Next, using (B.3), we formulate the developers' optimization problem as

$$\max_{\alpha,\beta,\gamma\in[0,1]} V_E(\alpha) \quad \text{s.t. } (B.3).$$

That is, by (B.5), developers maximize $S(\alpha)$ subject to the incentive constraint (B.4) and the financing constraint (B.3) (which binds in optimum) over $\alpha, \beta, \gamma \in [0, 1]$. Because equity and tokens are fairly priced, developers can extract all the surplus from the platform so that $V_E(\alpha)$ does not directly depend on $(\beta, \gamma)$. Thus, for any $\alpha$, it is optimal for developers to choose $(\beta, \gamma)$ to maximize $IC_E(\alpha)$. Due to (B.5), for given $(\beta, \gamma)$, it is optimal for developers to choose $\alpha$ to maximize $S(\alpha)$ subject to $IC_E(\alpha) \geq 0$. Because of $\bar{\alpha} = 1$ and $S'(\alpha) > 0$ for all $\alpha < 1$, the developers choose in optimum the maximum level of $\alpha$ that satisfies $IC_E(\alpha) \geq 0$.

Let $\alpha_{NE}$ denote the optimal level of security features without equity financing (i.e., with $\gamma = 1$ and $IC(\alpha_{NE}) \geq 0$). First consider that $\alpha_{NE} = 1$. Then the equity value is zero. Thus, raising funds by means of equity requires that $\alpha < 1$. However, setting $\alpha < 1$ is suboptimal because $\alpha = \bar{\alpha} = 1$ maximizes $S(\alpha)$ (see Assumption 1 and Lemma 1) and therefore $V_E(\alpha)$. Therefore, let us consider in the following that $\alpha_{NE} < 1$. By Assumption 1 and Lemma 1, absent frictions, the optimal choice of $\alpha$ is equal to $\bar{\alpha} = 1$. Thus, $\alpha_{NE} < 1$ implies that $IC(\alpha_{NE}) = 0$.

Next, take any $\alpha$ and 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 w.r.t. $\gamma$ to obtain

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

where we used the pricing relation $P_H = N_H\nu$, implied by $\nu r > \mu_H$ (see Assumption 2). We look at the incentive condition

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

and calculate

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

Thus, $dIC_E(\alpha_{NE})/d\gamma > 0$.

Also note that $V_E(\alpha)$ does not directly depend on $(\beta, \gamma)$. Choosing $\gamma = 1$ and $\beta$ to satisfy the financing constraint (3) yields payoff $V_E(\alpha_{NE})$, with $IC_E(\alpha_{NE}|\gamma = 1) = 0$ and $IC_E(\alpha|\gamma = 1) < 0$ for $\alpha \in (\alpha_{NE}, 1]$. If there existed $\alpha > \alpha_{NE}$ with $IC_E(\alpha|\gamma = 1) \geq 0$, then it would be optimal to increase token security features up to $\alpha$ as $S'(\alpha) > 0$ for all $\alpha \in [0, 1)$ (owing to Assumption 2 and Lemma 1), contradicting the optimality of $\alpha_{NE}$. Here, $IC_E(\alpha|\gamma = x)$ explicitly denotes the function $IC_E(\cdot)$, when tokens possess cash flow rights $\alpha$ and developers retain fraction $\gamma$ of equity.

Consider now that the developers choose $\gamma = \hat{\gamma} < 1$. Owing to $dIC_E(\alpha)/d\gamma > 0$ for $\alpha < 1$, it follows that $IC_E(\alpha|\gamma = \hat{\gamma}) < 0$ for $\alpha \geq \alpha_{NE}$. Thus, developers realize payoff bounded by $V_E(\alpha_E)$ with some $\alpha_E < \alpha_{NE}$. Because of Assumption 2 and Lemma 1 (i.e., $S'(\alpha) > 0$ for $\alpha \in [0, 1)$) and (B.5), it holds that $V_E(\alpha_E) < V_E(\alpha_{NE})$ so that setting $\gamma < 1$ is sub-optimal and raising funds by issuing equity next to tokens is suboptimal. □

### B.5. Proof of Proposition 4

*Proof.* By Proposition 2, $\alpha = 0$ maximizes the overall surplus if and only if $\nu r\xi \leq (1-\xi)\phi - \mu_H$. By Lemma 2, $\alpha = 0$ then also maximizes $\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}$, with $\beta = \beta_0$ satisfying (15).

Recall that the developers' incentive constraint reads

$$IC(\alpha) = \Lambda\left(\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r} - \beta P_L\right) - \kappa \geq 0.$$

Because in optimum $\beta = \beta_0$ solves (15) and $P_H$ strictly increases in $\alpha$ (see the token pricing Eq. (12)), it follows that $\beta$ increases in $\alpha$, while $P_L$ does not depend on $\alpha = 0$, due to $\mu_L = 0$ (see the token pricing Eq. (12)). Therefore, $\beta P_L$ increases in $\alpha$ and hence is minimized for $\alpha = 0$. As $\alpha = 0$ maximizes $\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}$, it follows that $\alpha = 0$ maximizes $IC(\alpha)$. As a result, when $\nu r\xi \leq (1-\xi)\phi - \mu_H$, $\alpha = 0$ maximizes both overall platform value (surplus) $S(\alpha)$ and incentives $IC(\alpha)$ and thus is optimal.

Next, an STO with $\alpha > 0$ maximizes the surplus $S(\alpha)$ if (see Proposition 2)

$$\bar{\alpha} > 0 \iff \nu r\xi > (1-\xi)\phi - \mu_H.$$

By Lemma 2, $\alpha > 0$ then also maximizes $\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}$, with $\beta = \beta_0$ satisfying (15). Then, $\alpha > 0$ is optimal when (in optimum) $IC(\alpha) > 0$, and the incentive constraint (13) does not affect the developers' optimization problem and so does not constrain the choice of $\alpha$ relative to the frictionless benchmark. This is the case if either $\kappa$, $1/\Lambda$, or $I$ is sufficiently small (for details, see proof of Claim 1 in Proposition 3). □

### B.6. Proof of Proposition 5

*Proof.* Recall that by Assumption 2 and Lemma 1, the value of a token-based platform is maximized for $\bar{\alpha} = 1$. In addition, we have that $\nu r > \mu_H$. The adoption level of a fiat-based platform equals $N^F := \left(\frac{A_H}{\phi}\right)^{\frac{1}{1-\xi}}$ and is, due to $\nu r > \mu_H$, always larger than the adoption level of a token-based platform, $N^T := \left(\frac{A_H}{\phi+\nu r-\alpha\mu_H}\right)^{\frac{1}{1-\xi}}$, for any $\alpha \in [0, 1]$. That is, $N^F > N^T$.

Consider the problem $\max_{\nu*\in\{0,\nu\}} S(\bar{\alpha})$, where $\nu$ is an exogenous parameter. This maximization problem can be solved by comparing the surplus (i.e., overall platform value) under a fiat-based platform, given by $\mathcal{A} := \frac{\mu_H}{r}\left(\frac{A_H}{\phi}\right)^{\frac{1}{1-\xi}}$, with the surplus under a token-based platform when $\alpha = \bar{\alpha} = 1$, given by $\mathcal{B} := \nu\left(\frac{A_H}{\phi+\nu r-\mu_H}\right)^{\frac{1}{1-\xi}}$.

Then, a fiat-based platform yields higher surplus than a token-based platform if and only if $\mathcal{A} \geq \mathcal{B}$, that is, if and only if $\frac{\mu_H}{\nu r} \geq \left(\frac{\phi}{\phi+\nu r-\mu_H}\right)^{\frac{1}{1-\xi}}$, which yields (23).

Recall that the developers' incentive constraint reads

$$IC(\alpha) = \Lambda\left(\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r} - \beta P_L\right) - \kappa \geq 0.$$

The arguments presented in the proof of Lemma 2 illustrate that maximizing $\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}$, with $\beta = \beta_0$ satisfying (15), is equivalent to maximizing the overall platform value (surplus) $S(\alpha)$. Thus, when (23) holds, then $\nu^* = 0$ also maximizes $\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}$, with $\beta = \beta_0$ satisfying (15). Owing to $\mu_L = 0$ and the pricing Eq. (12), it follows under a fiat-based platform with $\nu^* = 0$ that $P_L = 0$, whereas $P_L \geq 0$ under a token-based platform with $\nu^* = \nu$. That is, setting $\nu^* = 0$ minimizes the term $\beta P_L$, while maximizing $\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}$. As a result, when (23) holds, then $\nu^* = 0$ maximizes both the overall platform value (surplus) $S(\alpha)$ and the developers' incentives $IC(\alpha)$. Hence a fiat-based platform is optimal when (23) holds.

In contrast, when (23) does not hold, a token-based platform leads to higher surplus $S(\alpha)$, in that $\nu^*$ maximizes overall platform value. Hence, when (23) does not hold, then $\nu^* = \nu$ also maximizes $\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}$, with $\beta = \beta_0$ satisfying (15). It is therefore optimal to implement a token-based platform with $\nu^* = \nu$ if the incentive condition (13) does not affect the developers' optimization problem (i.e., does not constrain the optimal choice of $\nu^*$), which is the case if either $I, \kappa$, or $1/\Lambda$ is sufficiently low (for details, see proof of Claim 1 in Proposition 3).

We demonstrate under what conditions (23) is satisfied. Note that—owing to $\xi > 0$—(23) holds in the limit $\nu \to \infty$ and thus, by continuity, for sufficiently large $\nu$. Likewise, because $\nu r > \mu_H$, it follows that the RHS of (23) tends to zero as $\xi \to 1$, so that (23) holds for sufficiently large $\xi$.

Last, we analyze $\mu_H$ and define $f(\mu_H) : \mu_H \mapsto \frac{\mu_H}{\nu r} - \left(\frac{\phi}{\nu r-\mu_H+\phi}\right)^{\frac{1}{1-\xi}}$ and note that (23) holds whenever $f(\mu_H) \geq 0$. Observe that for $\mu_H = \nu r$, (23) holds in equality and $f(\mu_H) = 0$. Next, calculate $f'(\nu r) = \frac{1}{\nu r} - \frac{1}{(1-\xi)\phi}$, which is negative if and only if $\nu r > (1-\xi)\phi$. Thus, if $\nu r > (1-\xi)\phi$, it follows that $f(\mu_H) > 0$ and (23) holds in a left neighborhood of $\nu r$, that is, for $\mu_H < \nu r$ sufficiently large. Note that $\mu_H \geq \phi(1-\xi)$ implies $\nu r > \phi(1-\xi)$ due to $\nu r > \mu_H$. $\square$

## Appendix C. Token price volatility

### C.1. Proof of Corollary 6

*Proof.* Take $\bar{A} \in \{A_L, A_H\}$. First, assume that utility features pin down the token price in both states, $G, B$. This results into the equilibrium pricing system (25):

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

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

Linearize the above system (w.r.t. $\xi$ and $\mu(\cdot)$) to obtain

$$P_G = P_G(\alpha) = \nu\left(\frac{\bar{A}+\varepsilon_G}{\nu r - \alpha\mu(\bar{A}) + \phi - \nu\rho(P_B/P_G - 1)}\right) + o(\xi) + o(\max_A|\mu'(A)|),$$

$$P_B = P_B(\alpha) = \nu\left(\frac{\bar{A}+\varepsilon_B}{\nu r - \alpha\mu(\bar{A}) + \phi - \nu\rho(P_G/P_B - 1)}\right) + o(\xi) + o(\max_A|\mu'(A)|).$$

Discarding the terms $o(\xi) + o(\max_A|\mu'(A)|)$, this becomes a system of two linear equations, which can be solved for

$$P_G \simeq \frac{\nu\left(\bar{A}(\nu(2\rho+r) - \alpha\mu(\bar{A}) + \phi)\bar{A} + \varepsilon_G(\nu(r+\rho) - \alpha\mu(\bar{A})) + \varepsilon_B\nu\rho\right)}{\left(\phi - \alpha\,\mu(\bar{A}) + \nu r\right)\left(\phi - \alpha\,\mu(\bar{A}) + \nu(r+2\rho)\right)}$$

and

$$P_B \simeq \frac{\nu\left(\bar{A}(\nu(2\rho+r) - \alpha\mu(\bar{A}) + \phi)\bar{A} + \varepsilon_B(\nu(r+\rho) - \alpha\mu(\bar{A})) + \varepsilon_G\nu\rho\right)}{\left(\phi - \alpha\,\mu(\bar{A}) + \nu r\right)\left(\phi - \alpha\,\mu(\bar{A}) + \nu(r+2\rho)\right)},$$

where we omit the remainder terms of order $o(\xi) + o(\max_A|\mu'(A)|)$. One can then calculate that

$$\sigma \simeq P_G - P_B = \frac{\nu(\varepsilon_G - \varepsilon_B)}{\phi + \nu(r+2\rho) - \alpha\mu(\bar{A})},$$

$$\bar{\sigma} \simeq \frac{P_G - P_B}{0.5(P_G + P_B)} = \frac{2\,(\varepsilon_G - \varepsilon_B)\left(\nu r - \alpha\mu(\bar{A}) + \phi\right)}{\left(2\bar{A} + \varepsilon_G + \varepsilon_B\right)(\nu(r+2\rho) - \alpha\mu(\bar{A}) + \phi)},$$

showing that $\sigma$ and $\bar{\sigma}$ are increasing and convex in $\alpha$, when $\xi$ and $\max_A|\mu'(A)|$ are sufficiently small.

The second claim directly follows from the main text and in particular after some calculations, departing from expression (26). $\square$

### C.2. The problem before time $\tau$ with uncertainty after time $\tau$

Set $\bar{A} = A_H$. At time $\tau$, we have by assumption that $\mathbb{P}(\varepsilon_\tau = \varepsilon_G) = \mathbb{P}(\varepsilon_\tau = \varepsilon_B) = 1/2$. The solution to the model with persistent productivity shocks is then similar to that of Section 3 with the expected token price $\bar{P}$ and expected adoption levels $\bar{N}$, given by

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

replacing the token price $P_H$ and adoption level $N_H$.

## Appendix D. Micro-foundation for transaction protocol and holding period

### D.1. Micro-foundation 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, Li and Wang (2021).

*D.2. Micro-foundation for token holding period*

In the following, we give several potential ways to micro-found the holding period $\upsilon dt$. For the exposition, we consider our framework after the milestone, that is, $t > \tau$, 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 $\upsilon r > \alpha\mu_H$).

*D.2.1. Transaction settlement delays*

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

In our model, the value of any transaction is one dollar, that is, $1/P_t$ tokens. That is, $N_t$ is the number of dollar transactions 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 $\upsilon dt$ 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 initiated over the interval $[t - \upsilon dt, t)$ (and so are executed over $[t, t + \upsilon dt)$). The number of transactions initiated over $[t - \upsilon dt, t)$ equals

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

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 $t$, $\upsilon N_t$ transactions, that have been initiated yet not executed, require to hold one dollar in tokens, that is, $1/P_t$ dollars. Hence, the aggregate token demand equals $\upsilon N_t / P_t$, which, by virtue of market clearing, must equal the token market supply $1 - \beta_t$. Therefore, the token price equals

$$P_t = \frac{\upsilon N_t}{1 - \beta_t}.$$

*D.2.2. Deposits*

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

$$P_t = \frac{\upsilon N_t}{1 - \beta_t}.$$

## Appendix E. Cash diversion

Consider the following formulation of the moral hazard problem. Over $[t, t + dt)$, with probability $\Lambda dt$, the milestone $\tau$ arrives. If developers invest upon reaching the milestone amount $I > 0$, productivity becomes $A_t = A_H$ for $t \geq \tau$. If they invest less than $I$ or do not invest at all, productivity becomes $A_t = A_L$ for $t \geq \tau$. Thus, to develop the project and to reach high platform productivity, developers must raise amount $I$ at time zero and save/store this amount to be able to invest at the milestone. We assume stored/saved dollars to not earn interest. As in the baseline model, it is optimal not to hold more cash than necessary, that is, no more than $I$ dollars.

Following DeMarzo and Sannikov (2006), before time $\tau$, developers can secretly divert cash and receive per dollar diverted $\lambda \in [0, 1]$ dollars. After time $\tau$, platform cash flows are observable and there is no moral hazard problem anymore.

Given $\alpha$ and $\beta$, we analyze the developers' incentives to divert cash at any time $t$ before time $\tau$. It is clear that if cash diversion is optimal, then it is optimal to divert all cash $I$, yielding $\lambda I$ dollars. However, after diversion, the project has low productivity after the milestone and the price becomes $P_t = P_L = \upsilon N_L$. That is, at time $\tau$, developers earn $\beta P_L$ dollars from selling all retained tokens and $(1 - \alpha)\mu_L N_L / r$ dollars from future cash flows. Otherwise, if developers do not divert cash, token price equals $P_H = \upsilon N_H$ and they obtain $\beta P_H$ dollars from selling all retained tokens and $(1 - \alpha)\mu_H N_H / r$ dollars from future cash flows.

As at any time $t < \tau$ the expected time to reaching the milestone equals $1/\Lambda$, it follows that cash diversion is not optimal if and only if

$$\lambda I + \frac{\Lambda(\beta P_L + (1 - \alpha)\mu_L N_L / r)}{r + \Lambda} \leq \frac{\Lambda(\beta P_H + (1 - \alpha)\mu_H N_H / r)}{r + \Lambda}.$$

Rewriting yields

$$\Lambda\left(\beta P_H + \frac{(1 - \alpha)\mu_H N_H}{r}\right) - \lambda(r + \Lambda)I - \Lambda\left(\beta P_L + \frac{(1 - \alpha)\mu_L P_L}{r}\right),$$

which is similar to the incentive constraint in the baseline model, that is, (13). For $\lambda \equiv \frac{\kappa(r+\Lambda)}{I}$, this model variant in fact is isomorphic to the baseline model.

## Appendix F. Adverse selection

This appendix introduces adverse selection in our model by considering that there are two possible types of firms (i.e., platforms) operated by developers: a good platform, as described in the baseline version of the model, and a bad platform whose productivity after the milestone equals $A_t = A_L$ with $\mu_t = \mu_L$ with certainty. Both platforms require an initial investment $I$. The platform is good with exogenous probability $\pi \in [0, 1]$. Developers are privately informed about platform quality. Token investors only know the probability $\pi$ that a platform is good. Assumption 1 implies that good platforms are profitable and have positive NPV but bad platforms with low productivity $A_L$ are inefficient to finance and have negative net present value.

Let us start the analysis by looking for a separating equilibrium. In a separating equilibrium, the good firm grants cash flow rights $\alpha$ to token holders and retains tokens $\beta$, resulting in (state-contingent) adoption and token prices for $j = H, L$ after time $\tau$, given by

$$N_j(\alpha) = N_j = \left(\frac{A_j}{\max\{0, \upsilon r - \alpha\mu_j\} + \phi}\right)^{\frac{1}{1-\xi}}$$

and

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

In contrast, the bad firm chooses cash flow rights $\alpha_L$ and retention $\beta_L$. As the bad firm (platform) is inefficient (i.e., has negative NPV) and so does not receive financing, it follows that in a separating equilibrium, the payoff of a bad firm is equal to zero. On the other hand, mimicking the good firm and setting $\alpha_L = \alpha$ and retaining $\beta_L = \beta$ tokens yields strictly positive payoff $\frac{\Lambda\beta P_L}{r+\Lambda} > 0$. As a result, whenever the bad platform has negative NPV, a separating equilibrium does not exist. Therefore, we study in the following a pooling equilibrium.

### F.1. Pooling equilibrium

In a pooling equilibrium, both good and bad firms grant cash flow rights $\alpha$ to token holders and retain initially $\beta$ tokens. After time $\tau$, token price equals $P_H$ if the firm is of good type and developers exert sufficient effort and equals $P_L$ otherwise. As in the baseline model, we assume that exerting effort is efficient and therefore focus on pooling equilibria, in which a good firm has productivity $A_H$ after time $\tau$ and developers exert effort.

At time zero, given a fraction $\pi$ of good firms, the token price equals

$$\overline{p} := \frac{\Lambda}{r+\Lambda}(\pi P_H + (1-\pi)P_L).$$

Any firm sells at time zero the minimal amount of tokens needed to cover initial financing needs $I$, in that the retention level is given by

$$\beta = 1 - \frac{I}{\overline{p}}.$$

Adverse selection worsens the financing conditions of a good firm. As a consequence, with adverse selection, developers (operating a good firm) must sell more tokens $1-\beta$ at time zero to raise funds $I$, thereby reducing the retention level $\beta$ and developers' incentives.

For developers to have sufficient incentives to exert effort over $(0, \tau)$, the incentive condition (13) has to hold, that is,

$$IC(\alpha) := \underbrace{\Lambda\left(\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}\right) - \kappa}_{\text{Payoff under } a_t=1} - \underbrace{\Lambda\beta P_L}_{\text{Payoff under } a_t=0} \ge 0.$$

Recall that by assumption 1, $\mu_L = 0$. Finally, a good firm's problem boils down to solving

$$\max_{\alpha[0,1]} \Lambda\left(\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}\right) - \kappa \quad \text{s.t.} \quad IC(\alpha) \ge 0,$$

$$\beta = 1 - \frac{I}{\overline{p}}.$$

In contrast, a bad firm chooses $\alpha$ and $\beta$ to mimic a good firm, leading to (scaled) payoff $\Lambda\beta P_L > 0$. Because the bad firm's productivity is low with certainty, there is no moral hazard problem for bad type firms.

Fig. F.1 illustrates the effects of introducing adverse selection on outcome variables. The top panels show that adverse selection reduces the level of security features attached to tokens of good platforms for two reasons. First, due to adverse selection (which implies that $\overline{p} \le P_H$), developers must sell more tokens at time zero to cover their initial financing needs, leading to lower initial token retention $\beta$. To maintain incentive compatibility, developers, in turn, must possess more equity incentives, which requires them to grant less cash flow rights to token holders. Second, by increasing $\alpha$ and spurring platform adoption, developers of a good platform increase the token price $P_H$ but may reduce the average token price $P_H\pi + P_L(1-\pi)$. This is because granting cash-flow rights to token holders may reduce platform value in case the platform happens to be of low quality with $A_t = A_L$ for $t \ge \tau$. In fact, Proposition 2 highlights that granting cash-flow rights to token holders is only optimal if platform productivity is sufficiently high.

Fig. F.1 demonstrates that even mild adverse selection can lead to a substantial reduction in token security features $\alpha$ and developers' token retention $\beta$. In effect, we pick the value $\pi = 0.98$ as the base case because lower values of $\pi$ make it inefficient to finance the platform. Fig. F.1 also demonstrates that introducing adverse selection has no bearing on the predictions of the model regarding the effects of financing needs ($I$), the cost of effort ($\kappa$), or the expected time to platform development ($1/\Lambda$)) on the optimal level of retention ($\beta$) and token security features ($\alpha$).

### F.2. Alternative model assumptions and separating equilibrium

This section relaxes Assumption 1 by considering that the project has positive NPV and may produce cash flows with $\mu_L > 0$ even if developers do not exert effort, in that

$$\max_{\alpha\in[0,1]} \frac{\Lambda}{r+\Lambda}\left(P_L + \frac{(1-\alpha)\mu_L N_L}{r}\right) > I. \tag{F.1}$$

As a result, a bad platform with low productivity $A_L$ and cash flow rate $\mu_L$ has a positive NPV and receives financing in frictionless markets. Under this assumption, there can be a separating equilibrium. In the following, we assume that a bad platform has sufficiently low productivity and hence sufficiently low cash flows in that $\mu_L \le (1-\xi)\phi - \upsilon r\xi$, where $(1-\xi)\phi - \upsilon r\xi > 0$ so that under perfect information, it is optimal to set cash flow rights to

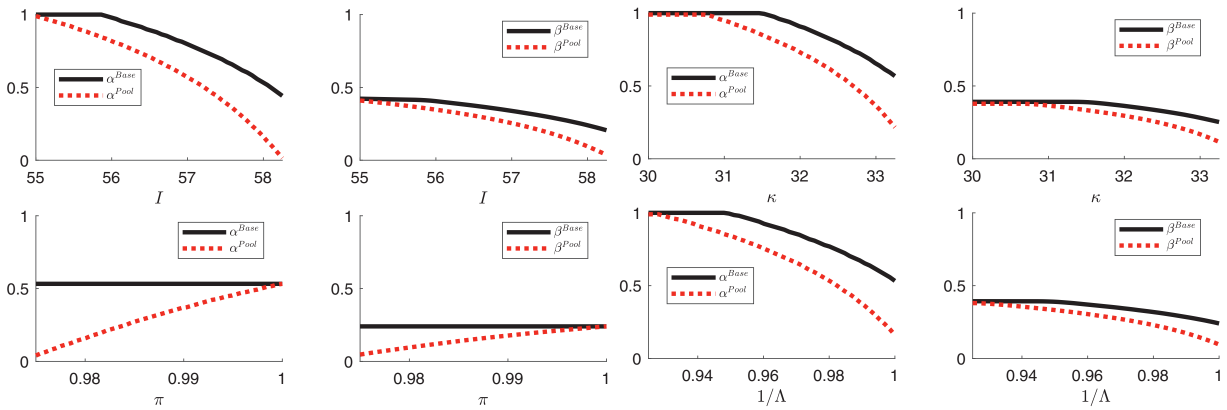


**Fig. F.1.** Comparison pooling equilibrium and baseline model.

$\alpha = \alpha_L \equiv 0$ for a bad type platform. Also recall that due to $\upsilon r > \mu_H \geq \mu_L$, it holds that $P_i = \upsilon N_i$ for $i = H, L$.

Consider first the problem of a bad type firm. By Proposition 2 (by replacing $\mu_H$ by $\mu_L$ in the statement of the proposition), it is optimal to set token security features of a bad platform to $\alpha_L = 0$ when a bad project receives financing because of $\mu_L \leq (1-\xi)\phi - \upsilon r\xi$. Developers' payoff is therefore given by

$$V_L := \frac{\Lambda}{r+\Lambda}\left(\upsilon + \frac{\mu_L}{r}\right)\left(\frac{A_L}{\upsilon r+\phi}\right)^{\frac{1}{1-\xi}} - I$$

$$= \frac{\Lambda}{r+\Lambda}\left(\beta_L\upsilon + \frac{\mu_L}{r}\right)\left(\frac{A_L}{\upsilon r+\phi}\right)^{\frac{1}{1-\xi}},$$

which is positive, by Eq. (F.1), and where developers' initial retention level satisfies

$$\beta_L := 1 - \frac{(\Lambda+r)I\upsilon}{\Lambda}\left(\frac{A_L}{\upsilon r+\phi}\right)^{\frac{-1}{1-\xi}}. \tag{F.2}$$

By (F.1) and the optimality of $\alpha = \alpha_L = 0$, it follows that $\beta_L \in [0, 1]$.

When there are no frictions, developers of a good platform optimally set $\alpha = 1$. In the presence of moral hazard, they choose the highest level of $\alpha \in [0, 1]$ that satisfies the incentive compatibility constraint $IC(\alpha) \geq 0$ (see Assumption 1 and Proposition 2). In addition, developers retain the maximum amount of tokens subject to their financing needs, in that $\beta = 1 - \frac{(\Lambda+r)I\upsilon}{\Lambda N_H}$.

By Proposition 2, platforms with low (high) cash flows optimally feature tokens with low (high) security features. Because a bad platform produces low cash flows, a high level of token security features may differentiate a good platform project from a bad one. In other words, token security features can serve as a signal for good platform quality. That is, the benefit of mimicking the high type is that the low type can sell tokens at a higher price at time zero and can thus retain more tokens (i.e., mimicking reduces the cost of investment). The cost of mimicking the high type is the increase in token security features, which reduces platform value (i.e., mimicking reduces the benefit of investment).

In the following, we therefore look for a separating equilibrium in which developers of a good platform choose $\alpha$ according to

$$\max \alpha \quad \text{s.t.} \quad IC(\alpha) \geq 0 \text{ and } \beta = 1 - \frac{(\Lambda+r)I\upsilon}{\Lambda N_H},$$

and developers of a bad platform choose $\alpha_L = 0$ and $\beta_L = 1 - \frac{(\Lambda+r)I\upsilon}{\Lambda}\left(\frac{A_L}{\upsilon r+\phi}\right)^{\frac{-1}{1-\xi}}$.

If it exists, this separating equilibrium is also the least cost separating equilibrium because in equilibrium, developers do not face additional optimization constraints (relative to the baseline model) and, in fact, solve (8). We also emphasize that because developers are risk neutral, token retention is not costly for platform developers and hence does not signal platform quality. Chod and Lyandres (2021) consider a risk-averse entrepreneur launching a platform. In their framework, token retention is costly for the entrepreneur, and there exists a separating equilibrium in which token retention signals a high platform quality. By assuming risk neutrality, we eliminate the signaling effect of token retention and highlight that token security features signal high platform quality too. Our findings can be viewed as complementary to those in Chod and Lyandres (2021).

In a separating equilibrium, it must hold that the bad type does not want to mimic the good type. When the bad type mimics the good type, it can sell tokens at time zero at a higher price and thus can retain more tokens, that is, $\beta > \beta_L$. The cost of mimicking the high type is that $\alpha$ increases, which reduces platform value. If the bad type does not mimic the good type, its payoff equals $V_L$. By contrast, its payoff upon mimicking the good type reads $V_L^{mimic} := \frac{\Lambda}{r+\Lambda}\left(\beta\upsilon + \frac{(1-\alpha)\mu_L}{r}\right)N_L$. In a separating equilibrium, the following must hold:

$$V_L \geq \frac{\Lambda}{r+\Lambda}\left(\beta\upsilon + \frac{(1-\alpha)\mu_L}{r}\right)N_L = V_L^{mimic}. \tag{F.3}$$

Moreover, provided that exerting full effort is efficient, the good type firm does not have incentives to mimic the bad type of firm. Hence, (F.3) is sufficient for the existence of the separating equilibrium. The reason is that in

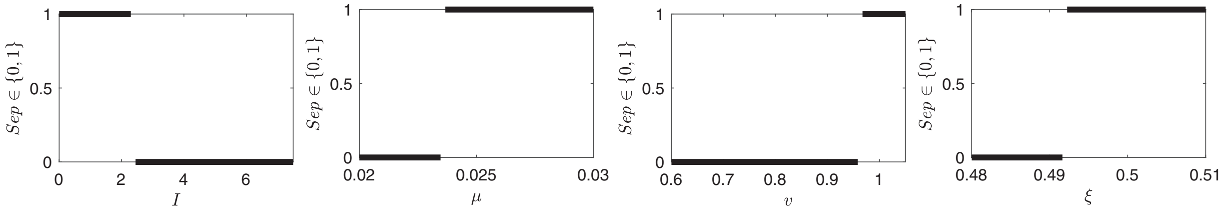


**Fig. F.2.** When does a separating equilibrium exist? $Sep = 1$ indicates that the prescribed separating equilibrium exists. Parameter values are set as in the base case environment except for $A_L = 0.9$ and $I = 1$ to ensure that the bad type platform has positive NPV.

the proposed separating equilibrium, the good type solves (8) and thus does not face additional optimization constraints (relative to the baseline model). That is, in the separating equilibrium, the good type already chooses the retention level $\beta$ and token security features $\alpha$ that maximizes her payoff subject to the incentive compatibility constraint (13) and the financing constraint (3). Therefore, the good type cannot do better by choosing different levels of $\beta$ and $\alpha$.

Fig. F.1 examines the effects of a firm's environment on the existence of a separating equilibrium. To make sure that the bad type platform has positive NPV, we depart from our baseline parameter values along two dimensions: we set $A_L = 0.9$ (instead of $A_L = 0.55$) and $I = 1$ (instead of $I = 58$). We also consider that cash flows are given by $\mu_H = \mu = 0.025$ and $\mu_L = 0$. Fig. F.1 shows that when financing needs are small, the separating equilibrium described above exists. Indeed, when financing needs $I$ are sufficiently low, $\beta$ and $\beta_L$ are low and so is the benefit of mimicking. In this case, (F.3) is satisfied, and the separating equilibrium exists. When $\kappa$ and $1/\Lambda$ are sufficiently large, the development effort is no longer efficient and the good type prefers to mimic the bad type so that there is no separating equilibrium. Fig. F.1 also shows that strong network effects ($\xi$), high platform transaction frictions ($v$), or a high cash flow rate ($\mu$) facilitate the existence of the separating equilibrium, in line with the above discussion.

In this separating equilibrium and provided that $\bar{\alpha} = 1$ (see Assumption 1), adverse selection does not change the optimal level of token security features $\alpha$ and the optimal retention level $\beta$ compared to the base case model. The reason is that signaling is de facto costless for the good type: the good type chooses the highest level of $\alpha$ satisfying incentive compatibility (13), which at the same time makes it (most) costly for the low type to mimic the high type. The following section relaxes Assumption 1 and considers parameter configurations with $\bar{\alpha} < 1$ so that adverse selection may boost the provision of token security features in a separating equilibrium.

As a result, adverse selection only affects the provision of token security features in the pooling equilibrium. Interestingly, adverse selection and moral hazard may interact and reinforce each other and hence jointly curb the provision of token security features. Moral hazard requires developers to possess sufficient equity incentives and leads to low token security features $\alpha$. Low token security features $\alpha$ make it attractive for the low type to mimic the high type, thereby destabilizing the separating equilibrium and leading to a pooling equilibrium, which exacerbates moral hazard and reduces token security features even further (as shown in F.1).

### F.3. Costly signaling

In the previous section, signaling is de facto costless for the good type firm, in that the good type firm finds it optimal to choose $\alpha \in [0,1]$ as high as possible, subject to incentive compatibility. This is a consequence of Assumption 2 that implies absent friction $\alpha = \bar{\alpha} = 1$ is optimal. This section considers parameter configurations such that $\bar{\alpha} < 1$ is optimal for the good type firm and $\alpha_L = 0$ is optimal for the bad type firm, absent frictions. That is, input parameter values are such that

$$\bar{\alpha} = \frac{vr}{\mu_H} + \frac{1}{\xi} - \frac{\phi(1-\xi)}{\xi\mu_H} \in (0,1).$$

In addition, we consider that $vr > \mu_H$, so tokens are priced according to utility features.

We look for a separating equilibrium in which the good type firm chooses token security features $\alpha$ and token retention $\beta$, while the bad type firm chooses token security features $\alpha_L = 0$ and token retention $\beta_L$ (with $\beta_L$ characterized in (F.2)). In the separating equilibrium, the bad type firm must not have incentives to mimic the good type firm so that (F.3) must hold. Next, consider the good type firm. In equilibrium, the good type firm's payoff equals

$$V_H := \frac{\Lambda}{r+\Lambda}\left(\beta v + \frac{(1-\alpha)\mu_H}{r}\right)N_H,$$

where $\beta = 1 - \frac{(\Lambda+r)Iv}{\Lambda N_H}$ and $N_H$ is a function $\alpha$, that is, $N_H = N_H(\alpha)$. Alternatively, the good type can pick a level of token security features $\alpha' \neq \alpha$, in which case the market perceives the good type firm as bad type firm. To cover initial financing needs $I$, the good type firm's retention level equals then $\beta_L$. As a result, upon deviating, the good type firm's payoff equals

$$V_H^{Dev} := \max_{\alpha' \in [0,1]} \left(\frac{\Lambda}{r+\Lambda}\left(\beta_L v + \frac{(1-\alpha')\mu_H}{r}\right)N_H\right),$$

subject to $IC(\alpha') \geq 0$, where $N_H$ is a function of $\alpha'$, that is, $N_H = N_H(\alpha')$. For the good type not to deviate, it must be that

$$V_H \geq V_H^{Dev}. \tag{F.4}$$

In a separating equilibrium, both (F.3) and (F.4) have to be satisfied.

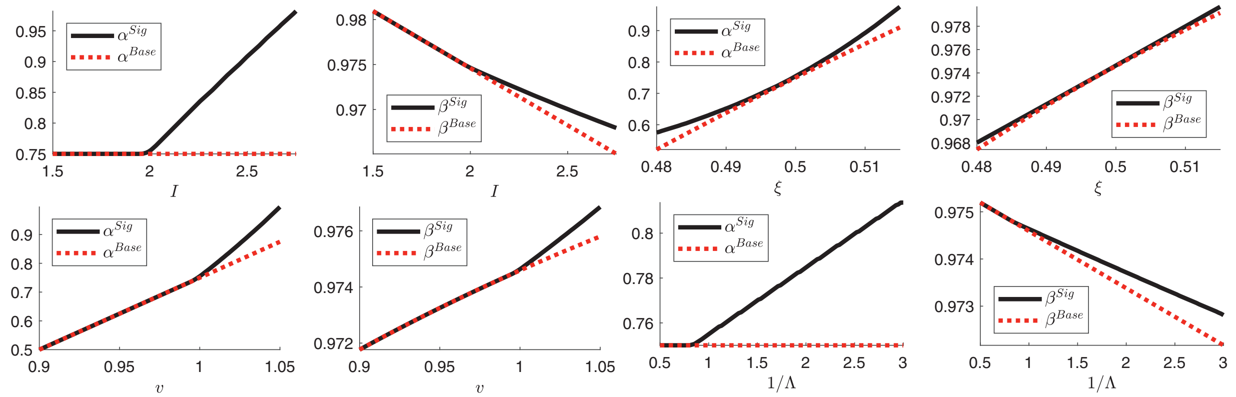


**Fig. F.3.** Comparison separating equilibrium and baseline model. We pick the parameters $I = 2 > 0 = \kappa$, $\mu_H = 0.2 > 0.1 = \mu_L$, and $A_L = 0.9$.

Provided there exists at least one separating equilibrium, we focus on the least cost separating equilibrium, which can be found by solving

$$\max_{\alpha\in[0,1]} V_H \quad \text{s.t.} \quad (F.3) \quad \text{and} \quad (F.4).$$

This amounts to

$$\min_{\alpha\geq\bar{\alpha}} \alpha \quad \text{s.t.} \quad (F.3) \quad \text{and} \quad (F.4).$$

In the following, we assume a separating equilibrium exists and compare the model outcomes in the least cost separating equilibrium with those of the baseline model.[16] Fig. F.2 illustrates that in the least cost separating equilibrium, the good type firm chooses higher $\alpha$ (i.e., $\alpha = \alpha^{Sig}$) than in the baseline model (i.e., $\alpha = \alpha^{Base}$). The reason is that by attaching high token security features, a good type firm signals good platform quality. Because a higher level of $\alpha$ boosts the token price, the good type firm's level of initial token retention $\beta^{Sig}$ in the least cost separating equilibrium is higher than in the baseline model, that is, than $\beta^{Base}$. The intuition is that a good type firm signals both by token retention and attaching security features to tokens. Fig. F.2 demonstrates that these effects are robust to parameter changes.

## Appendix G. 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

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

so the level of platform adoption becomes

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

when the platform charges transaction fees. In the following, we consider that developers cannot commit to future transaction fees. G.3 analyzes the case of full commitment. For simplicity, we abstract from moral hazard w.r.t. effort by taking sufficiently small $\kappa$, $1/\Lambda$ or $I$.

Without commitment, the optimal dynamic fee $f$ maximizes at each point in time $t \geq \tau$ the dividends accruing to developers

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

and therefore maximizes platform cash flows $(\mu_H + f)N_H$.[17] This leads to the following result:

*Proposition 7. The optimal dynamic fee for platform developers satisfies*

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

*If $(1-\xi)(vr+\phi) > \mu_H$, the fee increases in $\alpha$ for $\alpha \leq \alpha_1$ and decreases in $\alpha$ for $\alpha \geq \alpha_1$, where $\alpha_1 \in (0, 1)$ is the unique solution to*

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

*The resulting adoption level satisfies*

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

Proposition 7 shows that the optimal dynamic fee depends on whether the token utility or security features pin down the token price (i.e., whether $vr > \alpha(f + \mu_H)$ or $vr \leq \alpha(f + \mu_H)$, respectively). If $(1-\xi)(vr+\phi) > \mu_H$, the optimal fee follows a hump-shaped pattern in $\alpha$. The optimal level of security features with endogenous transaction fees is then characterized in the following corollary.

*Corollary 1. Tokens with $\alpha = 0$ are optimal if and only if*

$$(1-\xi)(\phi - \mu_H) \geq vr(\xi^{\frac{\xi}{\xi-1}} - 1). \tag{G.2}$$

*Tokens with $\alpha = 1$ are optimal if and only if condition (G.2) is not satisfied. Platform adoption is higher for $\alpha = 1$ than for $\alpha = 0$.*

[16] The question of the existence of a separating equilibrium was already discussed in the previous section.

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

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 $\alpha$ of the transaction fees flows back to users in the form of dividends. Higher $\alpha$ 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 a 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 $\alpha = 0$ is optimal.

Interestingly, the optimal transaction fee $f$ can be negative. In this case, the start-up firm subsidizes the user base to accelerate platform adoption.

*Corollary 2. Subsidies $f < 0$ are optimal if $\mu_H > \mathcal{S} := \frac{(1-\xi)(vr+\phi)}{1-\alpha\xi}$. If developers can commit to a fee structure $\{f\}$ at time zero, subsidies are optimal if $\mu_H > \mathcal{S} - \frac{vr}{1-\xi(1-\alpha)}$.*

As shown in Corollary 2, subsidies to the user base are more likely if the platform is financed with utility tokens (i.e., for $\alpha = 0$) or if the network effects are strong. In addition, subsidies are only optimal if the platform generates enough revenues $\mu_H$ to finance these subsidies. We also show that subsidies are more likely if the blockchain technology facilitates commitment.

### G.1. Proof of Proposition 7

*Proof.* Define $\varepsilon = 1/(1-\xi)$. Note that $N_H = \left(\frac{A_H}{\max\{0, vr - \alpha(\mu_H + f)\} + \phi + f}\right)^{\frac{1}{1-\xi}}$ and the optimal fee $f = f^*$ is such that $f^* = \arg\max_{f \geq 0} (\mu_H + f) N_H$.

1. Assume that $vr - \alpha(\mu_H + f) > 0$. Then, the FOC $\frac{\partial(\mu_H + f)N_H}{\partial f} = 0$ must hold in optimum. That is,

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

Thus, $(1-\alpha)f = \frac{(vr+\phi)(1-\xi) - \mu_H}{\xi} + \alpha\mu_H$ for optimal $f = f^*$.

Plugging the optimal fee expression into (G.1) yields the desired expressions for platform adoption, that is, $\left(\frac{A\xi}{vr+\phi-\mu_H}\right)^{\frac{1}{1-\xi}}$, and platform value (surplus), that is, $\left(v + \frac{(1-\xi)(vr+\phi-\mu_H)}{\xi r}\right)\left(\frac{A_H\xi}{\phi+vr-\mu_H}\right)^{\frac{1}{1-\xi}}$. Both expressions do not depend explicitly on $\alpha$. It follows that the developers' payoff and overall platform value (surplus) do not depend explicitly on $\alpha$ either.

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 $vr < \alpha(\mu_H + f)$, the FOC $\frac{\partial(\mu_H + f)N_H}{\partial f} = 0$ must hold so that

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

Otherwise, if $vr = \alpha(\mu_H + f)$, then $f = \frac{vr}{\alpha} - \mu_H = \frac{vr - \alpha\mu_H}{\alpha}$. Altogether, $f = f^* = \max\left\{\frac{vr - \alpha\mu_H}{\alpha}, \frac{(1-\xi)\phi - \mu_H}{\xi}\right\}$. Assumption 1 implies that $\frac{(1-\xi)\phi - \mu_H}{\xi} < \frac{vr}{\alpha} - \mu_H \Longleftarrow (1-\xi)(\phi - \mu_H) < vr\xi$; hence $f = f^* = \frac{vr - \alpha\mu_H}{\alpha}$.

In sum, we have shown that[18]

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

If $(1-\xi)(vr+\phi) > \mu_H$, the first expression in the "min" operator increases in $\alpha$, while the second expression decreases in $\alpha$. The first expression in the "min" operator tends to $\infty$ as $\alpha \to 1$, while the second one is always positive (due to $vr \geq \mu_H$) and tends to $\infty$ as $\alpha \to 0$. Hence, there exists a unique cutoff $\alpha_1 \in (0, 1)$ solving $\frac{(1-\xi)(vr+\phi) - (1-\alpha\xi)\mu_H}{\xi(1-\alpha)} = \frac{vr}{\alpha} - \mu_H$ (in $\alpha$). Below $\alpha_1$, the payoff does not explicitly depend on $\alpha$, as shown before. □

### G.2. Proof of Corollary 1

*Proof.* First, consider that $\alpha$ is such 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 $P_H = \frac{\alpha(\mu_H + f)N_H}{r} = vN_H$. This is the case when $\alpha = 1$. Thus, 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 $\alpha > 0$

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

Hence, $S'(\alpha) = 0$ is solved by $\varepsilon vr = vr + \alpha(\phi - \mu_H)$ so that $\alpha = \min\left\{\frac{\xi vr}{(1-\xi)(\phi - \mu_H)}, 1\right\}$ is optimal under these circumstances. Assumption 1 then implies that $\alpha = 1$, leading to adoption $N_H = \left(\frac{A_H}{\phi + vr - \mu_H}\right)^{\frac{1}{1-\xi}}$ and payoff (surplus) $v\left(\frac{A_H}{\phi + vr - \mu_H}\right)^{\frac{1}{1-\xi}}$. Note that for $\alpha = 1$, $f^* = vr - \mu_H$.

[18] For $\alpha = 1$, the expression for $f^*$ with some slight abuse of notation simply becomes $\frac{vr}{\alpha} - \mu_H$.

Second, consider $\alpha$ is such that $f^* = \frac{(1-\xi)(\upsilon r+\phi)-\mu_H}{\xi(1-\alpha)} + \frac{\alpha\mu_H}{1-\alpha}$. This is the case when $\alpha = 0$. In this case, the payoff does not depend on $\alpha$ (see previous results) and surplus (payoff) is given by $\left(\upsilon + \frac{(1-\xi)(\upsilon r+\phi-\mu_H)}{\xi r}\right)\left(\frac{A_H\xi}{\phi+\upsilon r-\mu_H}\right)^{\frac{1}{1-\xi}}$.

In sum, $\alpha \in \{0, 1\}$ is optimal. Note that $\alpha = 0$ is optimal for developers if it leads to higher overall platform value (i.e., surplus) than $\alpha = 1$ (as developers can extract all residual payoff). Thus, $\alpha = 0$ is optimal if

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

□

### G.3. Full commitment to transaction fees

Blockchain technology facilitates commitment to various metrics of platform and token design. For example, Cong, Li and Wang (2020b) 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.

In line with economic intuition, Corollary 3 shows that developers charge lower transaction fees and adoption is higher under full commitment.

*Corollary 3. Assume full commitment and $\phi > \mu_H$. Users incur the transaction fee*

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

*If $(1-\xi)\phi - \xi\upsilon r - \mu_H > 0$, the fee increases in $\alpha$ for $\alpha \leq \alpha_2$ and decreases in $\alpha$ for $\alpha \geq \alpha_2$, where $\alpha_2 \in (0, 1)$ is the unique solution to*

$$\frac{(1-\xi)\phi - \xi\upsilon r - (1-\alpha\xi)\mu_H}{\xi(1-\alpha)} = \frac{\upsilon r}{\alpha} - \mu_H.$$

*This implies the adoption level*

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

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.

*Corollary 4. Assume full commitment to fees $\{f\}$ and $\phi > \mu_H$. Then, $\alpha = 0$ is optimal if and only if*

$$(1-\xi)(\phi-\mu_H) \geq \upsilon r\left(\left(\frac{(\phi-\mu_H)}{(\phi-\mu_H+\upsilon r)\xi}\right)^{\frac{1}{1-\xi}}\xi^{\frac{\xi}{\xi-1}}\right). \tag{G.3}$$

*Otherwise, $\alpha = 1$ is optimal.*

#### G.3.1. Proof of Corollary 3

*Proof.*

1. Assume that $\upsilon r > (\mu_H + f)\alpha$. Under full commitment, developers choose the fee $f$ to maximize (given $\alpha$) $S(\alpha)$. Note that

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

In optimum, the FOC $\frac{\partial S(\alpha)}{\partial f} = 0$ must hold. We can solve for optimal $f = f^*$ via $(1-\alpha)f = \frac{\phi(1-\xi)-\mu_H-\xi\upsilon r}{\xi} + \alpha\mu_H$, leading to the adoption level $N_H^* = \left(\frac{A_H\xi}{\phi-\mu_H}\right)^{\frac{1}{1-\xi}}$.

2. Next, consider $\upsilon r \leq (\mu_H + f)\alpha$. If $\upsilon r = (\mu_H + f)\alpha$, then $f = \frac{\upsilon r}{\alpha} - \mu_H$ and $N_H^* = \left(\frac{A_H\xi}{\frac{\upsilon r}{\alpha}+\phi-\mu_H}\right)^{\frac{1}{1-\xi}}$. If $\upsilon r < (\mu_H + f)\alpha$, then $N_H = \left(\frac{A_H}{\phi+f}\right)^{\frac{1}{1-\xi}}$ and $P_H = \frac{\alpha(\mu_H+f)N_H}{r}$. We can without loss of generality assume that $\alpha = 1$. The FOC of maximization is

$$
\begin{aligned}
\frac{\partial S(\alpha)}{\partial f} &\propto (\mu_H + f)N_H'(f) + N_H(f) \\
&\propto 1 - \frac{1}{1-\xi}\frac{\mu_H + f}{\upsilon r + f} = 0.
\end{aligned}
$$

We can solve for $f = \frac{(1-\xi)\phi-\mu_H}{\xi}$.
Overall, if $\upsilon r \leq \alpha(\mu_H + f)$, then $f = f^* = \max\left\{\frac{(1-\xi)\phi-\mu_H}{\xi}, \frac{\upsilon r}{\alpha} - \mu_H\right\}$. Because of $\frac{(1-\xi)\phi-\mu_H}{\xi} < \frac{\upsilon r}{\alpha} - \mu_H \Longleftarrow (1-\xi)(\phi-\mu_H) < \upsilon r\xi$, we have that $f = f^* = \upsilon r/\alpha - \mu_H$.

In sum, we have shown that $f^* = \min\left\{\frac{(1-\xi)\phi-\xi\upsilon r-(1-\alpha\xi)\mu_H}{\xi(1-\alpha)}, \frac{\upsilon r}{\alpha} - \mu_H\right\}$, as desired. Consider the equation $\frac{(1-\xi)\phi-\xi\upsilon r-(1-\alpha\xi)\mu_H}{\xi(1-\alpha)} = \frac{\upsilon r}{\alpha} - \mu_H$. If $(1-\xi)\phi - \xi\upsilon r - \mu_H > 0$, the above equation possesses a unique solution on $\alpha_2 \in (0, 1)$. □

#### G.3.2. Proof of Corollary 4

*Proof.* As in the proof of Corollary 1, it suffices to compare payoffs under the polar cases $\alpha = 0$ and $\alpha = 1$. Notably, $\alpha = 0$ is optimal if and only if

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

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

$$\iff \frac{(1-\xi)(\phi-\mu_H)}{\xi \nu r} \geq \left(\frac{(\phi-\mu_H)}{(\phi-\mu_H+\nu r)\xi}\right)^{\frac{1}{1-\xi}}$$

$$\iff (1-\xi)(\phi-\mu_H)$$

$$\geq \nu r\left(\left(\frac{(\phi-\mu_H)}{(\phi-\mu_H+\nu r)\xi}\right)^{\frac{1}{1-\xi}} \xi^{\frac{\xi}{\xi-1}}\right).$$

□

*G.4. Proof of Corollary 2*

*Proof.* First, absent commitment, the fee levied reads $f^* = \min\left\{\frac{(1-\xi)(\nu r+\phi)-(1-\alpha\xi)\mu_H}{\xi(1-\alpha)}, \frac{\nu r}{\alpha} - \mu_H\right\}$, which is, due to $\nu r \geq \mu_H$, negative if and only if $\frac{(1-\xi)(\nu r+\phi)-(1-\alpha\xi)\mu_H}{\xi(1-\alpha)} < 0$, that is, if and only if $\mu_H > \mathcal{S} := \frac{(1-\xi)(\nu r+\phi)}{1-\alpha\xi}$.

Second, with full commitment to a fee structure at time zero, Proposition 4 implies the optimal fee is given by $f^* = \min\left\{\frac{(1-\xi)\phi-\xi\nu r-(1-\alpha\xi)\mu_H}{\xi(1-\alpha)}, \frac{\nu r}{\alpha} - \mu_H\right\}$, which is smaller than zero if and only if $\frac{(1-\xi)\phi-\xi\nu r-\mu_H}{\xi} + \alpha\mu_H < 0$, that is, if and only if $\mu_H > \mathcal{S} - \frac{\nu r}{1-\xi\alpha}$. □

## Appendix H. Dynamic trading

The objective of this appendix is to introduce richer trading dynamics in the model by considering the role of speculators. Specifically, we consider that there are risk-neutral speculators with discount rate $\rho < r$, capturing the notion that speculators are financially less constrained or more diversified than users and developers. Developers cannot commit at time zero to their trading of tokens.[19] In addition to speculators, we introduce convex costs of effort $\frac{\kappa a^2}{2}$ and assume that with effort $a \in [0, \bar{a}]$, the project succeeds at time $\tau$ and $A_t = A_H$ with probability $pa$ and the project fails at time $\tau$ with $A_t = A_L$ with probability $1 - pa$. The convex cost is needed to generate smooth trading patterns, as will become clear below. We impose that $\bar{a} \leq 1$ and $p \in (0,1)$ and assume throughout that optimal effort is interior.

We look for a Markov perfect equilibrium with state variable $\beta$, where $d\beta_t = \eta_t dt - \beta_t \mathbf{1}_{\{t=\tau\}}$. That is, developers optimally sell all retained tokens at time $\tau$ because, as in the baseline model, there is no moral hazard problem after time $\tau$. After time $\tau$, the token price (adoption level) is given by $P_H$ ($N_H$), if $A = A_H$, and is given by $P_L$ ($N_L$), if $A = A_L$. Before time $\tau$, the token price is a function of $\beta$, $P(\beta)$ and the developers' value function is also a function of $\beta$, $V(\beta)$; in addition, the developers trade tokens at endogenous rate $\eta_t$ for $t < \tau$.

Fix $\alpha$, which is chosen at time zero, and consider the developers' problem in state $\beta$. Define the developers' payoff from reaching the milestone with $A = A_i$:

$$T_i(\beta) := \beta P_i + \frac{(1-\alpha)\mu_i N_i}{r}.$$

This payoff consists of the value of token sales at the milestone, $\beta P_i$, and the present value value of future dividends, $\frac{(1-\alpha)\mu_i N_i}{r}$. Developers' value function $V(\beta)$ before time $\tau$ solves the following HamiltonJacobiBellman (HJB) equation

$$(r+\Lambda)V(\beta) = \max_{\eta,a}\Big\{\Lambda(paT_H(\beta) + (1-pa)T_L(\beta)) - \frac{\kappa a^2}{2} + \eta(V'(\beta) - P(\beta))\Big\}, \tag{H.1}$$

where the last term in the brackets captures the effects of trading. Thus, if effort $a$ is interior (i.e., $a < \bar{a}$), it is given by

$$a = \frac{\Lambda p}{\kappa}(T_H(\beta) - T_L(\beta)). \tag{H.2}$$

That is, incentives are captured by the difference $T_H(\beta) - T_L(\beta)$. It is easy to see that $T_H(\beta) - T_L(\beta)$ increases in $\beta$ so that token retention incentivizes effort.

Using arguments similar to those presented in DeMarzo and Urošević (2006), one can show that in equilibrium, developers are indifferent between buying and selling tokens. That is, $\frac{\partial V(\beta)}{\partial \eta} = 0$ whenever $\beta \in (0,1)$, that is,

$$P(\beta) = V'(\beta). \tag{H.3}$$

The reason is that developers' token sales exacerbate moral hazard and thereby depress platform value and token prices. As developers cannot commit to keeping tokens, they sell tokens and decrease the token price up to the point that they become marginally indifferent between buying and selling tokens. As such, in equilibrium, all gains from trade are dissipated by the subsequent rise in agency costs (this observation is also related to that in DeMarzo and He (2020) on the effects of changes in capital structure on shareholder wealth in a no-commitment equilibrium).

We can insert (H.2) and (H.3) back into Eq. (H.1) and solve for their value function in closed form:

$$V(\beta) = \frac{\Lambda T_L(\beta) + \frac{1}{2\kappa}(\Lambda p(T_H(\beta) - T_L(\beta)))^2}{r+\Lambda}.$$

Using (H.3) and differentiating the value function with respect to $\beta$, we obtain

$$P(\beta) = \frac{\Lambda T_L'(\beta) + \frac{(\Lambda p)^2}{\kappa}(T_H(\beta) - T_L(\beta))(T_H'(\beta) - T_L'(\beta))}{r+\Lambda}.$$

That is, the token price for $t < \tau$ is a function of $\beta$, in that $P_t = P(\beta_t)$. Before time $\tau$, speculators are marginal token investors. Since they are risk neutral, they simply need to be compensated for their time preference $\rho$, in that $\rho P_t dt = \mathbb{E} dP_t$. This can be written as

$$\rho P(\beta) = \Lambda(paP_H + (1-pa)P_L - P(\beta)) + P'(\beta)\eta.$$

[19] Similar results could be obtained by assuming instead that users discount at rate $\rho < r$ instead of $r$. However, to facilitate comparison with the previous sections, we introduce speculators. In line with this assumption, Fahlenbrach and Frattaroli (2020) show that tokens are held by both speculators and platform users.

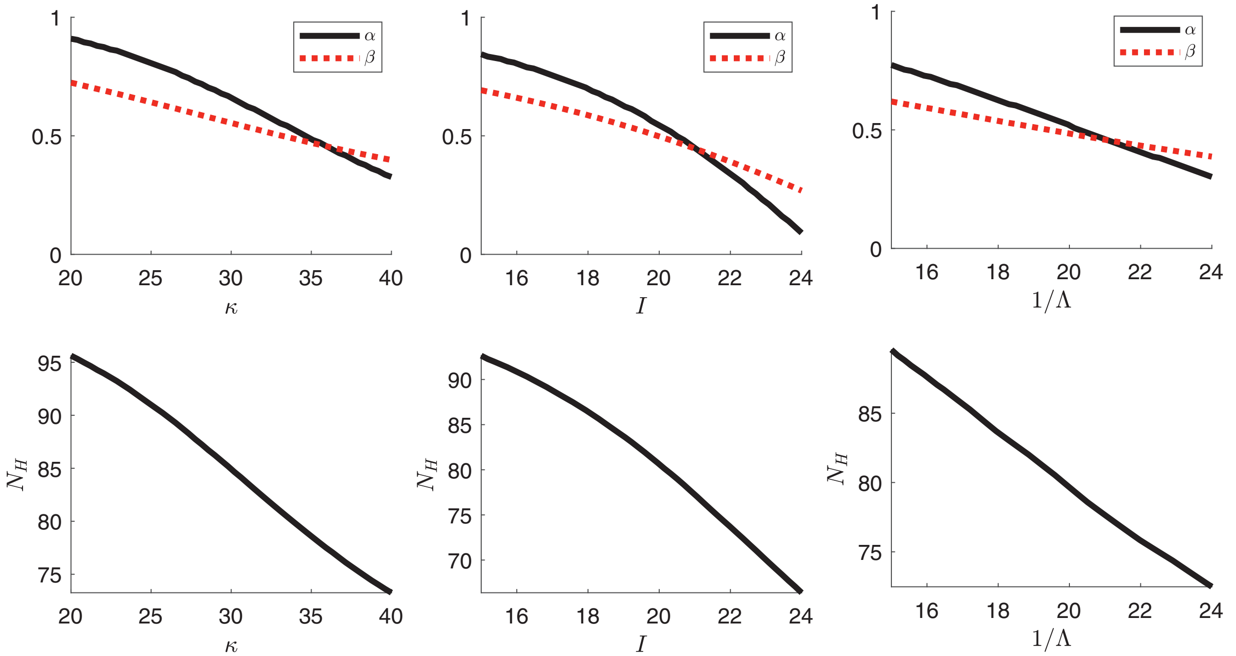


**Fig. H.1.** Model with optimal dynamic trading with $\kappa = 33.33$, $I = 20$, and $p = 0.5$.

Using this equation, we can solve for the trading rate $\eta$ in closed form:

$$\eta = \frac{(\rho + \Lambda)P(\beta) - \Lambda(paP_H + (1 - pa)P_L)}{P'(\beta)}.$$

As $\rho < r$ and there are gains for developers from selling tokens, it follows that $\eta < 0$. That is, developers optimally sell their token at a rate before the milestone is reached.

The initial retention level $\beta$ is set such that $(1 - \beta)P(\beta) = I$ and developers choose $\alpha$ to solve the problem

$$\max_{\alpha \in [0,1]} V(\beta).$$

We solve for the optimal value of $\alpha$ and initial retention $\beta = \beta_0$. Fig. H.1 presents the model outcomes for different values of $\kappa$, $I$, and $1/\Lambda$. As in the baseline version of the model, an increase of $\kappa$, $I$, or $1/\Lambda$ reduces the provision of security features $\alpha$ as well as the initial retention level $\beta$.

## Appendix I. Operating flow costs

Consider that instead of a cost $I$ at time zero, developers incur monetary flow costs $idt$ when developing the project over $[t, t + dt)$. There are no financing frictions and to cover these monetary flow costs, developers sell retained tokens. Developers can stop financing the platform, in which case it cannot be completed and future productivity equals zero. That is, for $t < \tau$, the milestone $\tau$ arrives with probability $\Lambda dt$ over $[t, t + dt)$ only if developers cover the development costs $idt$.

Starting with $\beta_0 = 1$ retained tokens at time zero, developers sell the retained tokens at rate $\eta < 0$ during platform development $[0, \tau)$ to cover development costs $idt$. In addition, developers sell all retained tokens at the milestone $\tau$. Formally,

$$d\beta_t = \eta_t dt - \beta_t \mathbf{1}_{\{t=\tau\}}.$$

We look for a Markov perfect equilibrium with state variable $\beta$. Before the milestone is reached (i.e., for $t < \tau$), the developers' value function $V(\beta)$ and the token price $P(\beta)$ are functions of $\beta$. To solve the model with flow costs, we first fix a level of $\alpha$ and solve for $V(\beta)$ and $P(\beta)$. We then select the optimal level of $\alpha$ by maximizing developers' payoff at time zero.

As in the baseline version, there is a moral hazard problem, in that developers must exert effort to achieve high platform productivity and exerting full effort is optimal in equilibrium. As a result, the incentive condition (13) must be satisfied:

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

Crucially, selling tokens reduces the retention level $\beta$, thereby undermining developers' incentives to exert effort. Because users and developers both discount at rate $r$, there are no gains from trade so that at any point in time $t < \tau$, developers sell the minimal amount of tokens that is needed to cover financing $i$, which maximizes incentives and thus is optimal. That is,

$$-\eta P(\beta) = i \iff \eta = \frac{i}{P(\beta)}.$$

For a given level of $\alpha$, the minimum level of retention $\underline{\beta}$ (depending on $\alpha$) required to maintain incentive compatibility satisfies $IC(\alpha) = 0$ so that

$$\underline{\beta} = \frac{\kappa}{\Lambda(P_H - P_L)} + \frac{(1-\alpha)(\mu_L N_L - \mu_H N_H)}{r(P_H - P_L)}.$$

In the following, we assume that i) $\underline{\beta} \geq 0$ and ii) the project is inefficient to finance when productivity is low. The latter assumption implies that platform development and financing is terminated once $\beta$ reaches $\underline{\beta}$ (and the project is never started when $\underline{\beta} \geq 1$).

Conditional on full effort, the developers' value function solves the ordinary differential equation (ODE)

$$(r+\Lambda)V(\beta) = \Lambda\left(\beta P_H + \frac{(1-\alpha)\mu_H N_H}{r}\right) + V'(\beta)\eta$$

subject to $V(\underline{\beta}) = 0$, while the token price solves the ODE

$$(r+\Lambda)P(\beta) = \Lambda P_H + P'(\beta)\eta,$$

subject to $P(\underline{\beta}) = 0$. The trading rate $\eta$ is given by $\eta = i/P(\beta)$. The solution to this system of coupled ODEs is not available in closed form.

Finally, the optimal level of token security features $\alpha$ is set to maximize developers' payoff at time zero $V(\beta_0) = V(1)$ so that developers solve

$$\max_{\alpha\in[0,1]} V(1).$$

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