NBER WORKING PAPER SERIES

TOKEN-BASED PLATFORM FINANCE

Lin William Cong
Ye Li
Neng Wang

Working Paper 27810
http://www.nber.org/papers/w27810

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
September 2020

We thank our conference discussants and conference/seminar participants at ABFER/CEPR/CUHK Financial Economics Symposium, AFA 2020, Carnegie Mellon University Tepper School of Business, Central Bank Research Association 2019 Meeting, CEPR ESSFM Gerzensee, Chicago Financial Institutions Conference, City University of Hong Kong, Cleveland Fed/OFR Financial Stability Conference, Cornell University, Econometric Society North America Annual Meeting (Atlanta), Erasmus Liquidity Conference, International Monetary Fund, Luohan Academy First Digital Economy Conference, Maastricht University, Macro Finance Society 14th Meeting, Midwest Finance Association (Chicago), SFS Cavalcade North America 2020, Stevens Institute of Technology, Tokenomics International Conference on Blockchain Economics, 4th Rome Junior Finance Conference, Security and Protocols, University of British Columbia (Economics Theory), University of Florida, USI Lugano, and University of Washington Bothell (Economics) for helpful comments and discussions. Will is grateful for the financial support from the Ewing Marion Kauffman Foundation. Ye is grateful for the financial support from Studienzentrum Gerzensee. The contents of this publication are solely the responsibility of the authors. The paper subsumes results from previous drafts titled “Token-Based Corporate Finance” and “Tokenomics and Platform Finance.” The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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NBER Working Paper No. 27810
September 2020
JEL No. E5,G3

ABSTRACT

We develop a dynamic model of platform economy where tokens derive value by facilitating transactions among users and the platform conducts optimal token-supply policy. Token supply increases when new tokens are issued to finance platform growth and to reward platform owners. Token supply decreases when the platform buys back tokens to boost the franchise value (seigniorage). Although token price is endogenously determined in a liquid market, the platform's financial constraint generates an endogenous token issuance cost that causes under-investment and conflicts of interest between insiders (owners) and outsiders (users). Blockchain technology improves efficiency by enabling commitment to predetermined rules of token supply that address the platform owners' time inconsistency and thereby mitigates under-investment.

Lin William Cong
Cornell University
Ithaca, NY 14853
will.cong@cornell.edu

Ye Li
The Ohio State University
Fisher College of Business
2100 Neil Ave
Fisher Hall 836
Columbus, OH 43210
United States
li.8935@osu.edu

Neng Wang
Columbia Business School
3022 Broadway, Uris Hall 812
New York, NY 10027
and NBER
nw2128@columbia.edu

1 Introduction

Digital platforms are reshaping the organization of economic activities. Traditional platforms rely heavily on payment innovations to stimulate economic exchanges among users. Recently, blockchain technology offers alternative solutions by allowing the creation of crypto-tokens as local currencies on platforms and the use of smart contracts that facilitate transactions among users and the financing of ongoing platform development.

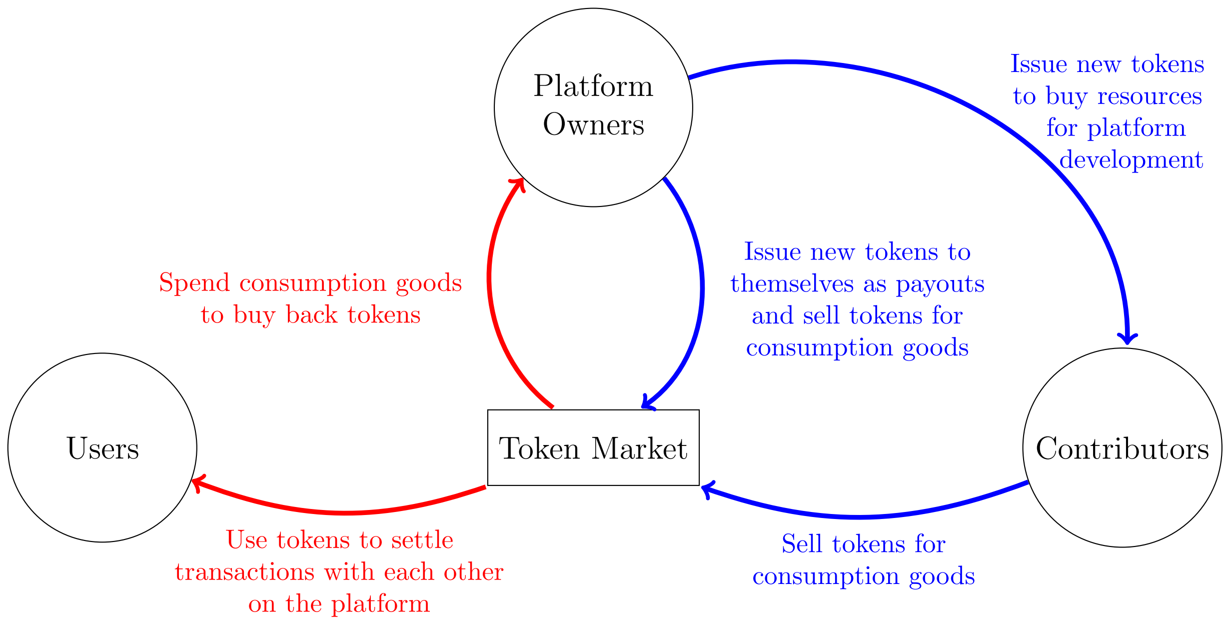

Figure 1: **Token Ecosystem**. The red and blue arrows represent token demand and supply, respectively.

We develop a dynamic model to capture key economic trade-offs of various platform participants and analyze the equilibrium dynamics of token-based communities. Figure 1 summarizes the circulation of tokens in our continuous-time platform economy.[1] All transactions are settled with native tokens. Users demand tokens as means of payment, enjoying convenience yields from token holdings while being exposed to the endogenous fluctuation of the token price. The platform owners, which include founding entrepreneurs, engineers, and key personnel, manage the token supply by solving a dynamic problem of investment, financing, and payout. The platform invests in the stochastic growth of productivity by issuing tokens to resource contributors (e.g., ledger validators and application developers). The owners also receive new tokens as payouts, but, may raise costly external funds to buy

[1] We thank our discussant Sebastian Gryglewicz for sharing with us this figure in his discussion slides.

back tokens and reduce the supply to sustain the token price. The token market-clearing condition determines the law of motion of the token price.

We focus on analyzing tokens as monetary assets that facilitate transactions in a fully dynamic setting rather than tokens as dividend-paying assets and their difference from traditional securities (e.g., Gryglewicz, Mayer, and Morellec, 2020). Our paper builds upon Cong, Li, and Wang (2020) (henceforth CLW). While CLW assume a fixed token supply (standard in the literature), this paper analyzes the optimal token supply and explore new questions on the dynamics of platform investment and financing, the conflict of interest between platform owners and users, and the role of blockchain technology in platform economics.

Our key contribution lies in providing a unified framework to jointly study the endogenous determination of token price and the optimal token-supply policies of digital platforms. The model setup applies to both traditional and blockchain-based platforms. The optimal token-supply policies are set to balance a realistic set of considerations, including investment in platform development, users' dynamic adoption, payouts to the owners, and potential financing costs involved in controlling the token supply through buy-back. Therefore, our results shed light on the rich variety of token-supply strategies in practice and offer normative implications on the optimal design of token-based platforms.

Our model delivers several unique insights on the economics of tokens and platforms. First, tokens are akin to durable goods but defy the Coasian prediction (Coase, 1972; Stokey, 1981; Bulow, 1982). The marginal cost of producing digital tokens is zero, but the equilibrium token price can be positive because the owners' concern over the franchise/continuation value provides sufficient incentive against over-supply and even induces the owners to raise costly external funds for token buy-backs. The key ingredients are the endogenous growth of platform productivity and the resulting user-base expansion through the network effects. Both are absent in the standard models of durable goods and stationary demand.

Second, under-investment in platform productivity arises from the conflict of interest between platform owners and users. In our model, token-financed investment in productivity increases the token supply as illustrated in Figure 1, but the resulting change of productivity is random. In equilibrium, the ratio of token supply to platform productivity, which is a measure of *excess* token supply, determines whether the owners receive token payouts (when the ratio is low) or pay the cost of external financing and buy back tokens (when the ratio is high). Following good shocks, productivity is improved, benefiting both the owners and users. Following bad shocks, the users are free to reduce token holdings or even abandon the platform, while the owners face an increase of excess token supply and a higher likelihood of future token buy-back financed by costly external funds. Such asymmetry decreases the owners' incentive to invest. Under-investment in turn reduces the users' welfare, the equilibrium token price, and eventually, the owners' value from token payouts.

The root of the under-investment problem is the owners' time inconsistency. If the owners were able to commit against under-investment, the users would have demanded more tokens, which then increases the token price and the value of owners' token payouts. However, a predetermined level of token-financed investment can be deemed sub-optimal ex post as the likelihood of costly token buy-back evolves. Therefore, the discretion in token supply can destroy value. Discretionary token supply was the norm of traditional platforms.[2]

Blockchain technology enables commitment to predetermined rules of token supply, and thus, can address the platform owners' time inconsistency. We compare our baseline model of discretionary supply with a case of predetermined token supply that is motivated by Ethereum (one of the most popular blockchain applications by token market capitalization). We find that the owners' value is indeed improved under the predetermined token supply.

Our paper is the first to show the value of commitment enabled by the blockchain technology. That said, we recognize that in practice, blockchain commitment is far from perfect, so it is important to consider both predetermined and discretionary token supply. While some platforms restrict the maximum of token supply, such caps are typically large, leaving the gradual release of token reserves under the discretion of platform designers. Moreover, platform designers are often entitled to a significant fraction of total allocation, through which they can influence token supply despite various vesting schemes.[3]

Next, we further elaborate on the model mechanisms. The users' convenience yield from token holdings increases in platform productivity. To capture network effect, a distinguishing feature of platform businesses, we allow the convenience yield to depend on the aggregate number of users ("user base"). The user base evolves endogenously for two reasons. First, the stochastic growth of productivity directly affects users' participation. Second, users' expectation of future token price varies over time. An intertemporal complementarity amplifies the effects of productivity growth on the equilibrium dynamics — when potential users expect productivity growth and more users to join in future, they expect token price to appreciate and thus have stronger incentive to participate now.

The platform's investment in productivity is financed by tokens. Therefore, tokens not

[2]For example, Blizzard, the gaming behemoth, sets the maximum of tokens the game players can purchase. The supply of QQ coins was continuously set by Tencent as well.

[3]Appendix B illustrates the discretionary allocation with examples including that of the Kin foundation which dynamically manages token distribution to the founders, app developers, marketers etc.

only enable users to transact with one another, but also serves as financing instruments. The platform can increase token supply and pay the new tokens to a pool of dispersed contributors for their efforts and resources that improve productivity.[4] Because the contributors sell tokens to users who value the convenience yield and thus are the natural buyers, the amount of resources the platform can raise by issuing tokens depends on the token price. Token price is determined endogenously by the users' token demand and the platform's token supply.

The owners' value is the present value of tokens paid to themselves net of the costs of token buy-backs. In a Markov equilibrium, the owner's value is a function of the current platform productivity and token supply, which are the two state variables. The owners' marginal value of productivity is positive, capturing the equilibrium dynamics of users' adoption and valuation of tokens. The marginal value of token supply is negative due to the downward pressure on token price. The owners derive value from future token payout, and thus, resist against over supply that depresses the token price. The owners may even find it optimal to buy back tokens and burn them out of circulation in order to protect their continuation value.[5] In equilibrium, the owners receive token payout when token supply is low relative to platform productivity and buy back tokens when token supply is relatively high.

A key friction in our model is that when buying back tokens, the platform owners have to raise costly external funds. While token buyback occurs occasionally, the associated financing cost propagates into a *dynamic token issuance cost* in every state of the world because every time more tokens are issued, the platform owners' expectation of costly future buyback changes accordingly. Specifically, the owners' cost of issuing one more token, i.e., the marginal decline of continuation value, is larger than the market price of tokens, i.e., the users' valuation of tokens. This wedge causes the platform to under-invest in productivity.

In our model, tokens are perfectly liquid. For example, newly issued tokens are not subject to discounts due to informational asymmetry. They are simply valued by the marginal user's indifference condition. Despite the perfect liquidity, tokens are not immune to financial frictions. The token issuance cost emerges because the founders' optimal buy-back relies on costly external funds. In other words, the optimal strategy of token management transmits

[4]Our focus on decentralized contributions is consistent with the vision of major token-based platforms that once the platform launches, the founding entrepreneurs' contributions tend to be limited relative to the decentralized contributors', such as KIN, a blockchain-based social network, and TON, a payment network

[5]Burning tokens means sending them to a public "eater address" from which they can never be retrieved because the address key is unobtainable. Practitioners often burn tokens to boost token price and reward token holders (e.g., Binance and Ripple). Some also use Proof-of-Burn as an environmentally friendly alternative to Proof-of-Work to generate consensus (e.g., Counterparty (XCP) blockchain), or destroy unsold tokens or coins after an ICO or seasoned token issuances for fair play (e.g., Neblio's burning of NEBL tokens).

the traditional costs of external financing into an endogenous cost of token issuance.

The dynamic token issuance cost implies a conflict of interest between owners and users. A productivity enhancement paid with new tokens benefits users via a higher convenience yield. But more tokens in circulation now implies a higher likelihood of costly token buy-back in the future. Therefore, while the owners bear the costs of future token buy-back, the benefits of token-financed investment are shared with users. Admittedly, part of such benefits flow to the owners through a higher token price (and higher value of token payout), but the owners cannot seize all surplus from users — users are heterogeneous in deriving convenience yield from tokens, so only the marginal user breaks even while those who derive more convenience yield enjoy a positive surplus.[6] *Token overhang*, i.e., under-investment due to the surplus leakage to users, is a fundamental feature of token-based financing.

After characterizing the optimal token-management strategy (i.e., investment, payout, and buyback), we analyze the value of introducing blockchain technology in our setting. Blockchains distinguish themselves from traditional technologies in several aspects: immutable record keeping due to time-stamping and linked-list data structure, smart contracting for automating and ensuring execution, and distributed design for easier monitoring and decentralized governance. These features enable the commitment of predetermined token-supply rules that, we show, are valuable in addressing the under-investment problem.

Specifically, motivated by Ethereum, we consider a constant growth of token supply that finances investment. We find that commitment mitigates the under-investment problem by severing the state-by-state linkage between investment and the dynamic token issuance cost. While the increased amount of tokens issued for investment results in more frequent costly token buyback, the owners' value is higher than the case with discretionary token supply, because the token price is higher under faster trajectories of productivity and user-base growth. Previous studies of tokens assume predetermined rules of supply. In contrast, our analysis starts from the fully discretionary supply of tokens. By comparing the discretionary case with the predetermined case, we are able to identify the value-added of commitment and to partly explain the popularity of blockchain technology among the platform businesses.

Finally, our model also has implications on the design of stablecoins. Different from the existing approaches based on collateralization, the platform owners in our setting support their franchise value by occasionally buying back tokens out of circulation. When the token

[6]The intuition is related to the surplus that a monopolistic producer forgoes to consumers when price discrimination is impossible. Here tokens are traded at a prevailing price among competitive users, so the platform owners cannot extract more value from users who derive a higher convenience yield from tokens.

supply is high relative to the platform productivity — precisely at the moment that token price is low but the marginal value of reducing token supply is high — the buy-back happens. The resulting token supply dynamics moderate the token price fluctuations.

Overall, by analyzing a token ecosystem, our model reveals key trade-offs in the dynamic allocation of tokens. It also provides a guiding framework for practitioners: The various token offering schemes observed in practice can be viewed as special (sub-optimal) cases. Appendix B discusses the institutional background and offers a rich set of real-life examples.

Literature. The most related paper is Gryglewicz, Mayer, and Morellec (2020) which also studies endogenous platform productivity but focuses on the founders' efforts rather than decentralized contributors'. Mayer (2020) further introduces speculators and study the conflict of interests among various token holders. Our paper differs from Gryglewicz, Mayer, and Morellec (2020) in the following aspects. While they consider hybrid tokens that facilitate transactions and pay dividends, we study tokens that only serve as means of payment. We also focus on a different stage of platform life-cycle and different forms of uncertainty. In their paper, the uncertainty is in the exogenous Poisson time of platform launching and the token price is constant post-launch. We study a post-launch platform with uncertainty from Brownian productivity shocks, and we model the endogenous fluctuation of token price. Finally, while they consider a fixed token supply, we characterize the optimal state-contingent supply of tokens and highlight the value of commitment brought by blockchains.

We connect the literature on platform economics to dynamic corporate finance, especially the studies emphasizing the role of financial slack and issuance costs (e.g., Bolton, Chen, and Wang, 2011; Décamps, Gryglewicz, Morellec, and Villeneuve, 2016). Instead of cash management, we analyze platforms' token-supply management when platform investment induces user network effects and, very importantly, the token price varies endogenously as users respond to token-supply variation.[7] From a methodological perspective, our paper is related to Brunnermeier and Sannikov (2016) and Li (2017) who study the endogenous price determination of inside money (deposit contracts) issued by banks. The key distinction is that tokens are outside money instead of liabilities of the issuing platforms.

Our paper contributes to the broad literature on digital platforms. Studies on traditional platforms (e.g., Rochet and Tirole, 2003) do not consider the use of tokens as platforms' native currencies (local means of payment).[8] We share the view on platform tokens with

[7] Related to Cagan (1956), the platform owner essentially maximizes the present value of seigniorage flows.
[8] Stulz (2019) reviews the recent financial innovations by major digital platforms.

Brunnermeier, James, and Landau (2019) – a platform is a currency area where a unique set of economic activities take place and its tokens derive value by facilitating the associated transactions.[9] Beyond this, we emphasize that a platform can invest in its quality, for example, payment efficiency (Duffie, 2019), and thereby, raise token value. Our paper is the first to formally analyze how platforms manage their investment and payout through token supply, and provide insights into the incentives and strategies of platform businesses.

Our paper adds to emerging studies on blockchains and cryptocurrencies. We endogenize token supply and incorporate platform owners' long-term interests (franchise value).[10] By doing so, we are able to provide the first unified theory of optimal platform monetary, investment, and payout policies with both token price and user base being endogenously determined. We also demonstrate the commitment value of blockchains.[11] Furthermore, our paper adds to the discussion on token price volatility and stablecoins. On the demand side, high token price volatility could be an inherent feature of platform tokens due to technology uncertainty and endogenous user adoption (see CLW).[12] Saleh (2018) emphasizes that token supply under proof-of-burn (PoB) protocols can reduce price volatility. We endogenize both the demand for platform tokens driven by users' transaction needs and dynamic adoption, and the supply of tokens for platform development and the founders' to extract profits. We show that the optimal token supply strategy stabilizes token price.

Finally, our paper is broadly related to the literature on crowdsourcing and the gig economy. Blockchain-based consensus provisions in the form of cryptocurrency mining and resources (capital) raised via initial coin offerings (ICOs) are salient examples of decentralized on-demand contributions. Existing studies on ICOs and crowdfunding focus on one-time issuance of tokens before the platform launches (e.g., Garratt and Van Oordt, 2019; Chod and Lyandres, 2018; Canidio, 2018), yet platforms increase token supply on an on-going

[9] Our model differs from the majority of monetary-policy models because tokens are issued to finance investment as in Bolton and Huang (2017) and reward platform owners rather than to stimulate nominal aggregate demand or alleviate liquidity shortage.

[10] The studies on the design issues of tokens (e.g., proof-of-work protocols) typically assume a fixed user base (e.g., Chiu and Wong, 2015; Chiu and Koeppl, 2017). A fixed token supply is a common feature among the models that study the roles of tokens among users and contributors (e.g., miners in Sockin and Xiong, 2018; Pagnotta, 2018) and the existing models of token valuation (e.g., Fanti, Kogan, and Viswanath, 2019).

[11] Even though commitments through tokens can be valuable in various settings (e.g., Goldstein, Gupta, and Sverchkov, 2019), in practice, the reliability of blockchain and the associated commitment value are not free of costs (Abadi and Brunnermeier, 2018). As analyzed by Biais, Bisiere, Bouvard, and Casamatta (2019), proof-of-work protocols can lead to competing records of transactions ("forks"). Saleh (2017) analyzes the forks of proof-of-stake blockchains and finality of transactions. Ferreira, Li, and Nikolowa (2020) show that blockchain governance can be compromised by dominant miners. Commitment is often implemented via smart contracts, for which Cong and He (2018) provide some examples.

[12] Hu, Parlour, and Rajan (2018) and Liu and Tsyvinski (2018) document the token price dynamics.

basis. Existing studies also center around the founders' hidden efforts or asymmetric information pre-launch, whereas we emphasize decentralized contributors' effort post-launch that is highly relevant for digital platforms and the gig economy.[13] This distinction is a key consideration in determining whether tokens are securities or not based on the Howey Test.[14]

2 Model

There are three types of agents in a continuous-time economy: an entrepreneur (used interchangeably with "platform owner"), a pool of contributors, and a unit measure of users. The owner designs the platform's protocol. Contributors, who represent miners (transaction ledger keepers), app developers, and other providers of on-demand labor in reality, devote efforts and resources required for the operation and continuing development of the platform. Users conduct peer-to-peer transactions and realize trade surpluses on the platform. A generic consumption good serves as the numeraire.

2.1 Platform Productivity and Contributors

We study a dynamically evolving platform whose productivity (quality), A_t, evolves as

$$\frac{dA_t}{A_t} = L_t dH_t, \tag{1}$$

where L_t is the decentralized contribution (resources and labor) invested into productivity growth by the platform and dH_t is a shock to investment efficiency,

$$dH_t = \mu^H dt + \sigma^H dZ_t. \tag{2}$$

Here Z_t is a standard Brownian motion that generates the information filtration of this economy. The platform productivity A_t broadly captures marketplace efficiencies, network security, processing capacity, regulatory conditions, users' interests, the variety of activities feasible on the platform, etc. It therefore affects directly users' utility on the platform, which

[13] The entrepreneurs in the ICO models do not engage in dynamic token management for long-term platform development, and thus, do not concern the franchise value. Despite newly issued tokens from platforms, decentralized contributors such as miners can also receive transaction fees (Easley, O'Hara, and Basu, 2019; Basu, Easley, O'Hara, and Sirer, 2019; Huberman, Leshno, and Moallemi, 2019; Lehar and Parlour, 2020).

[14] For example, SEC sued Telegram/TON that raised US$1.7 billion through a private placement for not complying with securities laws (Michaels, 2019). The issue boils down to whether investors in tokens post-launch expect to profit from the entrepreneurs' effort or decentralized contributions discussed in our paper.

shall be made clear shortly. We consider a stochastic economy to better capture reality and to explore the model's implications on the volatility of token price.

Platform productivity grows through L_t, which may represent labor or capital inputs, as described in Appendix B. The investment efficiency, dH_t, may result from the the entrepreneur's effort in designing the platform before it was launched, and thus, it represents the entrepreneur's essential human capital. As discussed in the literature review, in contrast to studies on founders' pre-launch efforts, we take H_t as given and emphasize efforts and resources, L_t, from decentralized contributors compensated with tokens post launch.

Our focus is on the dynamic interaction between the owners and users, so we do not explicitly model contributors' decision-making but instead specify directly the required numeraire value of payment for L_t to be $F(L_t, A_t)$, which is increasing and convex in L_t and may also depend on A_t. Let P_t denote the unit price of token in terms of the numeraire (consumption goods). Given A_t, to gather a contribution of L_t, the platform issues $F(L_t, A_t)/P_t$ units of new tokens to workers. Let M_t denote the total amount of circulating tokens (token supply). The payment for L_t adds to the growth of token supply, dM_t, by $F(L_t, A_t)/P_t$.

The functional form of $F(\cdot)$ depends on the structure of labor or capital markets that the platform participates in. A distinguishing feature of labor supply in a "gig economy" is that workers provide on-demand contributions and receive token payments instead of long-term employment contracts.[15] Here tokens facilitate the acquisition of labor by allowing the platform to pay for labor *on the spot* and thereby avoiding the limited commitment on the part of platform that arises in the implementation of deferred compensation and may lead to complex legal enforcement issues especially when workers and the platform belong to different judicial areas. Moreover, since digital tokens are often programmable (via smart contracting), escrow accounts can be set up and enforced automatically so that tokens are released to workers only if their inputs (e.g., programming codes or solutions to cryptography puzzles) are received. Therefore, tokens also reduce the platform's exposure to workers' limited commitment.[16] Finally, L_t also represents the capital received from crowd-based investors, for example through initial or seasoned token offerings. Investors receive tokens immediately on the spot instead a promise of payoff in the future, thus avoiding any

[15]Workers may represent miners in Proof-of-Work-based public blockchains or drivers on ride-sharing apps.

[16]Another reason to introduce tokens as means of payment for L_t is the heterogeneity in labor quality. Consider a subset of workers supply high-quality efforts because they understand better the technologies behind the platform. Naturally, these capable workers assign a higher value to tokens because they are not concerned about the adverse selection problem that low-quality workers face due to their lack of technological knowledge. In other words, in contrast to cash-based compensation, token-based compensation screens out high-type workers and thereby improves the match between employer (the platform) and employees (workers).

exposure to the platform's failure to deliver future payouts of traditional contracts.

The concern of dilution naturally arises – workers and investors who receive tokens may worry about token depreciation because the platform may issue more tokens in the future. In other words, while tokens avoid limited commitments by facilitating spot payments, the platform's lack of commitment against excess token supply is still a concern. Our analysis of optimal token supply addresses this question, but first let us introduce platform users.

2.2 Platform Users

In our model, after receiving tokens, workers and investors may immediately sell tokens to users. Workers and investors who contribute L_t can also be users themselves, and the model is not changed at all as long as the utility from token usage and the disutility from contributing L_t (which gives rise to $F(\cdot)$) are additively separable.

As in CLW, users can conduct transactions by holding tokens. We use $x_{i,t}$ to denote the value (real balance) of agent i's holdings in the unit of numeraire. By facilitating transactions, these holdings generate a flow of utility (or convenience yield) over dt given by

$$x_{i,t}^{1-\alpha} \left(N_t^{\gamma} A_t u_i\right)^{\alpha} dt, \tag{3}$$

where N_t is the platform user base, u_i captures agent i's idiosyncratic needs for platform transactions, and $\alpha, \gamma \in (0,1)$ are constants. Following CLW, we provide a theoretical foundation for this specification of transaction surplus in Appendix A. A crucial difference from CLW is that we endogenize A_t and the token supply M_t.

The flow utility of token holdings depends on N_t, the total measure of users on the platform with $x_{i,t} > 0$.[17] This specification captures the network externality among users, such as the greater ease of finding trading or contracting counterparties in a larger community.

We assume that users' transaction needs, u_i, are heterogeneous. Let $G_t(u)$ and $g_t(u)$ denote the cross-sectional cumulative distribution and density function respectively that are continuously differentiable over a support $[\underline{U}_t, \overline{U}_t]$ and may vary over time. u_i can be broadly interpreted: For payment blockchains (e.g., Ripple and Bitcoin), a high value of u_i reflects user i's needs for international remittance; for smart-contracting platforms (e.g., Ethereum),

[17] One is example involves a producer who accepts tokens as means of payment and earns net profits equal to the full transaction surplus. The profits depend on the scale of operation, i.e., the sales $x_{i,t}$, and variables that determine the profit margin, which include the total outreach, N_t, the platform efficiency A_t, and the producer's idiosyncratic productivity u_i.

u_i captures user i's project productivity, and token holdings facilitate contracting;[18] ;or decentralized computation (e.g., Dfinity) and data storage (e.g., Filecoin) applications, u_i corresponds to the need for secure and fast access to computing power and data.

As P_t denotes the unit price of token in terms of the numeraire, we let $k_{i,t}$ denote the units of token that user i holds so the *real balance*

$$x_{i,t} = P_t k_{i,t}. \tag{4}$$

To join the platform (i.e., $k_{i,t} > 0$), a user incurs a flow cost ϕdt. For example, transacting on the platform requires attention; account maintenance and data migration also take effort. Therefore, agents with sufficiently high u_i choose to join the platform, while agents with sufficiently low u_i do not participate.

Let $y_{i,t}$ denote user i's *cumulative* utility from platform activities. We follow CLW to assume that the users are well-diversified so that their transaction surpluses on the platform are priced by an exogenous stochastic discount factor. Thus we can interpret the equilibrium dynamics as dynamics under the risk-neutral measure, and write user i's objective as

$$\mathbb{E}\left[\int_0^\infty e^{-rt} dy_{i,t}\right], \tag{5}$$

where we can write the incremental utility $dy_{i,t}$ as follows:

$$dy_{i,t} = \max\left\{0, \max_{k_{i,t}>0}\left[(P_t k_{i,t})^{1-\alpha}\left(N_t^\gamma A_t u_i\right)^\alpha dt + k_{i,t}\mathbb{E}_t\left[dP_t\right] - \phi dt - P_t k_{i,t} r dt\right]\right\}. \tag{6}$$

The outer "max" operator in (6) reflects user i's option to leave and obtain zero surplus from platform activities, and the inner "max" operator reflects user i's optimal choice of $k_{i,t}$. For the special case where users are risk neutral, the risk-neutral measure is the same as the data-generating probability (physical measure).

Inside the inner max operator are four terms that add up to give the incremental transaction surpluses from platform activities. The first term corresponds to the blockchain trade surplus given in (3). The second term is the expected capital gains from holding $k_{i,t}$ units of tokens. Users care about the sum of the on-chain transaction surplus and the expected token appreciation given by the first two terms in (6). The third term is the participation

[18] For example, in a debt contract, the borrower's Ethereum can be held in an escort or "margin" account, which is automatically transferred to the lender in case of default. Posting more Ethereum as margin allows for larger debt contracts, which in turn lead to projects of larger scale and profits.

cost, and the last term is the financing cost of holding $k_{i,t}$ units of tokens.

It is worth emphasizing that platform users must hold tokens for at least an instant dt to complete transactions and derive utility flows, and are therefore exposed to token price change over dt. Appendix B contains motiving examples and institutional details.

2.3 The Entrepreneur

The entrepreneur represents the founding developers and initial investors who own the platform and design its protocol that includes the development strategy $\{L_t, t \geq 0\}$. Over time, the entrepreneur receives a *cumulative* number of tokens D_t as dividends and, similar to users, evaluates the tokens with a risk-neutral objective function and discount rate r:

$$\max_{\{L_t, D_t\}_{t\geq 0}} \int_{t=0}^{+\infty} \mathbb{E}\left[e^{-rt} P_t dD_t \left[\mathbb{I}_{\{dD_t \geq 0\}} + (1+\chi)\,\mathbb{I}_{\{dD_t < 0\}}\right]\right]. \tag{7}$$

When $dD_t > 0$, the entrepreneur receives token dividends that have a market value P_t per unit.[19] Note that in equilibrium, the entrepreneur immediately sells her tokens to users who derive an extra convenience yield from token holdings. In line with our interpretation of H_t resulting from the entrepreneur's design efforts prior to launching the platform, token payout can be understood as a form of compensation for their essential human capital.

We allow the entrepreneur to buy back and burn tokens to reduce the token supply (i.e., $dD_t < 0$). By reducing token supply, the owner can boost token price, and consequently increase the value of future token dividends. A higher token price also allows the platform to gather more resources for productivity growth in the future. When $dD_t < 0$, the entrepreneur raises external financing (numeraire goods) at a proportional cost χ to buy back tokens.[20]

Considering both the token issued for investment L_t and the entrepreneur's dividend/buy-back, we have the key accounting identity that describes the evolution of token supply:

$$dM_t = \frac{F(L_t, A_t)}{P_t} dt + dD_t. \tag{8}$$

[19] For example, blockchain behemoth Bitmain Technologies Ltd and Founders Fund (known for early bets on SpaceX and Airbnb) invest in EOS and hold ownership stakes that entitle them for future token rewards. The gradual distribution of token dividends can be viewed as contingent vesting in reality – a certain amount of total tokens D_t have been allocated by time t but are distributed over time (via dD_t) depending on the stages of platform development and the tokens outstanding (i.e., different values of A_t and M_t).

[20] The parameter χ may also represent the forgone consumption and other investment opportunities. It is consistent with Bolton, Chen, and Wang (2011) who also model in reduced form the information, incentive, and transactions costs that a firm incurs whenever it raises real resources from external equity market.

When the platform invests (first term of right side) or distributes token dividends (second term of right side), the total amount of tokens in circulation increases; the token supply decreases when the entrepreneur burns tokens out of circulation. Later we show that the platform owner's financial slack varies with M_t due to the financing cost χ, so the token stock is akin to the cash inventory in Bolton, Chen, and Wang (2011), except that the token price is endogenous and the financial slack decreases in M_t.

In what follows, we characterize a Markov equilibrium with the platform productivity A_t and the token supply M_t as state variables.

Definition 1. *A Markov equilibrium with state variable A_t and M_t is comprised of agents' decisions and token price dynamics such that the token market clearing condition holds, users optimally decide to participate (or not) and choose token holdings, contributors supply resources for the compensation of $F(L_t, A_t)$ in numeraire value, and the platform strategies, i.e., L_t and D_t, are optimally designed to maximize the owner's value.*

3 Dynamic Equilibrium

In this section, we first derive the platform owners' optimal investment and token payout and buyback, which in turn pin down the token supply. We then derive platform users' optimal decisions on adoption and token holding in order to aggregate token demand. Finally, token market clearing yields the equilibrium dynamics of token price.

3.1 Optimal Token Supply

At time t, the owner's continuation or franchise value V_t (i.e., the time-t value function) satisfies the following Hamilton–Jacobi–Bellman (HJB) equation:

$$rV(M_t, A_t)\,dt = \max_{L_t, dD_t} P_t dD_t \left[\mathbb{I}_{\{dD_t \geq 0\}} + (1+\chi)\,\mathbb{I}_{\{dD_t < 0\}}\right] + V_{M_t}\left[\frac{F(L_t, A_t)}{P_t}dt + dD_t\right] \quad (9)$$
$$+ V_{A_t} A_t L_t \mu^H dt + \frac{1}{2} V_{A_t A_t} A_t^2 L_t^2 (\sigma^H)^2 dt.$$

The first term in this HJB equation reflects the platform's dividend payout ($dD_t > 0$) and buyback ($dD_t < 0$). When there are more tokens circulating, the token price tends to be low, and so does the owner's continuation value. Therefore, we expect $V_{M_t} < 0$, which we later confirm in the numerical solution. Payout occurs only if $-V_{M_t} \leq P_t$, i.e., the marginal cost of increasing token supply is not greater than the market value of token. Buyback happens when $-V_{M_t} \geq P_t(1+\chi)$, i.e., when the marginal benefit of decreasing token supply is not less than the cost of burning tokens. The second term is the product of marginal value of token supply, V_{M_t}, and the drift of token supply, which consists of tokens paid to contributors and tokens distributed to or burned by the entrepreneur. The third term is the marginal benefit of an A_t increase. The platform productivity increases in labor L_t, which is the mean productivity of $A_t\mu^H dt$. But hiring labor using tokens increases the token supply M_t, which has a marginal cost of $V_{M_t}\frac{F_{L_t}}{P_t}dt$ as $V_{M_t} < 0$. Moreover, labor productivity is uncertain, so the fourth term captures how such risk enters into the choice of L_t. The next proposition summarizes the platform's optimal policies.

Proposition 1 (**Optimal Token Supply**). *The optimal token supply strategy is given by the optimal L_t solved implicitly as a function of state variables, A_t and M_t, by*

$$V_{A_t}A_t\mu^H + V_{A_tA_t}A_t^2 L_t^* \left(\sigma^H\right)^2 = F_L\left(L_t^*, A_t\right)\left(\frac{-V_{M_t}}{P_t}\right) \tag{10}$$

and the optimal dD_t—the entrepreneur receives token payouts ($dD_t^* > 0$) only if $P_t \geq -V_{M_t}$, and buys back and burns tokens out of circulation ($dD_t^* < 0$) only if $-V_{M_t} \geq P_t(1+\chi)$.

Equation (10) equates the marginal benefit of investment to the marginal cost. The left side is the marginal impact on the drift of A_t, evaluated by the entrepreneur's marginal value of A_t growth and adjusted for the risk of productivity shock via the second term.

The right side is the marginal cost of investment. Since the entrepreneur's marginal cost of token supply can be larger than the market value of tokens, the physical marginal cost F_L is multiplied by $-V_{M_t}/P_t$. This multiplier reflects a *token issuance cost*. Here the platform pays for investment with "undervalued" tokens. The payout/buy-back policy in Proposition 1 implies that $V_{M_t}/P_t \in [1, 1+\chi]$. Because the entrepreneur incurs a financing cost $\chi > 0$ when burning tokens, there exists a region of (M_t, A_t) such that $V_{M_t}/P_t > 1$, i.e., a token issuance cost exists. As will be shown in the solution, the condition $-V_{M_t} \geq P_t$ holds in strict inequality almost everywhere. We have the following corollary that highlights the link between off-platform capital markets and the platform's token issuance cost.

Corollary 1 (**Token Issuance Cost**). *The entrepreneur's off-platform financing cost χ leads to a token issuance cost: When $\chi > 0$, there exists a positive measure of (M_t, A_t) such that the token issuance cost is positive, i.e., $-V_{M_t}/P_t > 1$. This issuance cost distorts the investment policy by amplifying the marginal cost of investment as shown in Equation (10).*

Token issuance cost arises even though the token market is perfectly liquid. The financing cost creates conflict of interest between insiders (entrepreneur/platform owners) and outsiders (users). Productivity enhancement paid with new tokens benefits users via a higher convenience yield. More tokens in circulation now implies a higher likelihood of token buyback and incidence of financing cost in future. While the owners bears the financing cost, the benefits are shared with users. Admittedly, part of such benefits flow to the owners through a higher token price (and higher value of expected token payout), but the owners cannot seize all surplus from users. Users are heterogeneous in deriving convenience yield from tokens, so only the marginal user breaks even after token price increases while those who derive more convenience yield enjoy a positive surplus.

The intuition is related to the surplus that monopolistic producer forgoes to consumers when price discrimination is impossible. Here tokens are traded at a prevailing price among competitive users, so the platform owners cannot extract more value from users who derive a higher convenience yield than the marginal token holder.

Token overhang, i.e., under-investment due to the leakage of surplus to users, is the fundamental characteristic of token-based financing. Uncertainty also plays a critical role here. Without dZ_t, the productivity shock, L_t, always increases A_t. Then, with a sufficiently efficient investment technology $F(\cdot)$ (so that very few new tokens are needed to pay for L_t), we arrive at a situation where, following investment, A_t always grows faster than M_t, and thus, the platform always moves away from costly buyback. As a result, the financing cost is never a concern given this sufficiently efficient $F(\cdot)$. However, in the presence of uncertainty in investment outcome, there always exists a probability that M_t increases faster than A_t after investment, moving the platform closer to costly buyback.

In sum, the mechanism of token overhang relies on three ingredients in the model. First, when platform owners raise consumption goods to buy tokens out of circulation, they face a financing cost. Second, users are heterogeneous in deriving convenience yield from token holdings, and a single token price is formed in a unified token market through competitive trading. Third, the outcome of platform investment is uncertain. The first ingredient creates a private cost of investment for platform owners, and the second implies a surplus leakage to users. Together, they generate conflict of interest between owners and users. Finally, the third ingredient, uncertainty, is needed so that in spite of the specification of $F(\cdot)$, token overhang always exists.

Before ending the analysis of token supply, we emphasize that our characterization of the optimal investment and payout/buyback policies allays the concern over fraudulent designs by founding developers and the resulting explosion of token supply that destroys token value. One might worry that the entrepreneur has strong incentive and ample opportunity to build "back doors" in the protocol that allow them to steal tokens when tokens become valuable. The stolen tokens are likely to be sold in secondary markets for dollars, and thus, depress the token price. However, as shown in Proposition 1, our setup already allows the entrepreneur to extract token as dividends and the optimal payout policy maximizes the owner's value, so it is an incentive-compatible rewarding scheme for the founding designers. In other words, we characterize a subgame perfect equilibrium between a large player (the platform) and a continuum of small players (users). From a regulatory perspective, any proposal of blockchain or platform design should disclose the schemes of payout to the founding developers and they should be broadly in line with the above characterization.

3.2 Optimal Token Demand

We conjecture and later verify that in equilibrium, the token price, P_t, evolves as

$$dP_t = P_t\mu_t^P dt + P_t\sigma_t^P dZ_t, \tag{11}$$

where μ_t^P and σ_t^P are endogenously determined. Agents take the price process as given under rational expectation. Conditioning on joining the platform, user i chooses the optimal token holdings, $k_{i,t}^*$, by using the first order condition,

$$(1-\alpha)\left(\frac{N_t^\gamma A_t u_i}{P_t k_{i,t}^*}\right)^\alpha + \mu_t^P = r, \tag{12}$$

which states that the sum of *marginal* transaction surplus on the platform and the expected token price change is equal to the required rate of return, r.

Rearranging this equation, we obtain the following expression for the optimal token holdings:

$$k_{i,t}^* = \frac{N_t^\gamma A_t u_i}{P_t}\left(\frac{1-\alpha}{r-\mu_t^P}\right)^{\frac{1}{\alpha}}. \tag{13}$$

$k_{i,t}^*$ has several properties. First, agents hold more tokens when the common productivity, A_t, or agent-specific transaction need, u_i, is high, and also when the user base, N_t, is larger due to network effects. Equation (13) reflects an investment motive to hold tokens, that is $k_{i,t}^*$ increases in the expected token appreciation, μ_t^P.

Using $k_{i,t}^*$, we obtain the following expression for the user's maximized profits conditional on participating on the platform:

$$N_t^{\gamma} A_t u_i \alpha \left(\frac{1-\alpha}{r-\mu_t^P} \right)^{\frac{1-\alpha}{\alpha}} - \phi. \tag{14}$$

User i only participates when the preceding expression is non-negative. That is, only those users with sufficiently large u_i participate. Let $\underline{u}_t$ denote the type of the marginal user, then

$$\underline{u}_t = \underline{u}\left(N_t; A_t, \mu_t^P\right) = \frac{\phi}{N_t^{\gamma} A_t \alpha} \left(\frac{r-\mu_t^P}{1-\alpha} \right)^{\frac{1-\alpha}{\alpha}}. \tag{15}$$

The adoption threshold $\underline{u}_t$ is decreasing in A_t because a more productive platform attracts more users. The threshold also decreases when agents expect a higher token price appreciation (i.e., higher μ_t^P). Because only agents with $u_i \geq \underline{u}_t$ participate, the user base is then

$$N_t = 1 - G_t\left(\underline{u}_t\right). \tag{16}$$

Equations (15) and (16) jointly determine the user base N_t given A_t and μ_t^P. Note that zero adoption is always a solution, and trivially leads to zero token price.

Proposition 2 (**Token Demand and User Base**). *Given A_t and μ_t^P, the platform has a positive user base if Equations (15) and (16) have solutions for $\underline{u}_t$ and N_t. Conditional on participating, User i's optimal token holding, $k_{i,t}^*$, is given by Equation (13). The token holding, $k_{i,t}^*$, decreases in P_t and increases in A_t, μ_t^P, u_i, and N_t.*

To obtain the numerical solution, we later specify $G_t(u)$ and explicitly derive N_t.

3.3 Token Market Clearing

Clearing the token market determines the token price. Let us define the *participants' aggregate transaction need* as

$$U_t := \int_{u \geq \underline{u}_t} u g_t(u)\, du, \tag{17}$$

the integral of u_i of participating agents.

The market clearing condition is

$$M_t = \int_{i \in [0,1]} k_{i,t}^* di. \tag{18}$$

Substituting optimal holdings in Equation (13) into the market clearing condition in Equation (18), we arrive at the *Token Pricing Formula*.

Proposition 3 (Token Pricing). *The equilibrium token price is given by*

$$P_t = \frac{N_t^{\gamma} U_t A_t}{M_t} \left(\frac{1-\alpha}{r - \mu_t^P} \right)^{\frac{1}{\alpha}}. \tag{19}$$

The token price increases in N_t – the larger the user base is, the higher trade surplus individual participants can realize by holding tokens, and stronger the token demand. The price-to-user base ratio increases in the platform productivity, the expected price appreciation, and the network participants' aggregate transaction need, while it decreases in the token supply M_t.[21] Equation (19) implies a differential equation for P_t on the state space of (M_t, A_t). This can be clearly seen once we apply the infinitesimal generator to the token price, $P_t = P(M_t, A_t)$, in the Markov equilibrium to express μ_t^P into a collection of first and second derivatives of P_t by Itô's lemma. Note that the equilibrium user base, N_t, is already a function of A_t and μ_t^P as shown in Proposition (2). Therefore, the collection of token market clearing conditions at every t essentially characterize the full dynamics of token price.

Equations (8) and (18) describe the primary and secondary token markets. The change of M_t is a flow variable, given by Equation (8), that includes the new issuances from platform investment and payout and the repurchases by the entrepreneur. The token supply M_t is a stock variable, and through Equation (18), it equals the token demand of users.

Discussion: durable-good monopoly. The problem faced by token-based platform reminisces the classical durable-good monopoly problem (e.g., Coase, 1972; Stokey, 1981; Bulow, 1982). Indeed, token-based platforms share several characteristics with durable-good monopolists. First, token issuance permanently increases the total supply, so when issuing tokens to finance investment or payout, platform owners are competing with future selves. Second, the physical cost of creating tokens is zero, so it seems that platform owners can be tempted to satisfy the residual token demand by ever lowering token price as long as the price is positive, i.e., above the marginal cost of production. Given that users rationally form

[21] The formula reflects certain observations by practitioners, such as incorporating DAA (daily active addresses) and NVT Ratio (market cap to daily transaction volume) in token valuation framework, but instead of heuristically aggregating such inputs into a pricing formula, we solve *both* token pricing and user adoption as an equilibrium outcome. See, for example, *Today's Crypto Asset Valuation Frameworks* by Ashley Lannquist at Blockchain at Berkeley and Haas FinTech.

expectation of future token price, users may wait for lower prices, which in turn implies that platforms flood the market with tokens immediately after launching, driving token price to zero. This is the classic Coase intuition. However, in our model, platforms pay out tokens to owners gradually, only at the payout boundary, and voluntarily buy back and burn tokens out of circulation. Such token-supply policies result in a positive and stationary token price.

Our model differs from the Coasian setting in two aspects. First, even though the physical cost of producing tokens is zero, the dynamic token issuance cost increases in the token supply as will be shown in the next section. This reminisces the result in Kahn (1986) that the Coase intuition does not hold in the presence of increasing marginal cost of production. Second, in contrast to theories of durable-good monopoly, token demand in our model is not stationary; in fact, given the geometrical growth of A_t due to platform investment, token demand grows exponentially. Therefore, users cannot expect lower token price in the future. Moreover, because reversing token issuance through burning incurs a financing cost, the real-option consideration under uncertainty in A_t further deters excessive token supply. In sum, what distinguishes our model from models of durable-good monopoly is the endogenous growth of platform productivity. As will be shown in Section 4, A_t and M_t are cointegrated in the Markov equilibrium, so the platform does try to take advantage of the expanding token demand driven by productivity growth but does not over supply.

4 Equilibrium Characterization

We further characterize the equilibrium by analytically deriving and numerically solving the system of differential equations concerning token price and platform owners' value function. To streamline exposition and focus on core economic insights, we make some simplifying parametric assumptions.

4.1 Parametric Choices

Following the literature on investment in finance and macroeconomics (e.g., Bolton, Chen, and Wang, 2011), we assume a convex (quadratic) investment cost function of F:

$$F\left(L_t, A_t\right) = \left(L_t + \frac{\theta}{2} L_t^2\right) A_t, \tag{20}$$

where $\theta > 0$ can depend on the elasticity of labor and capital supply. In comparison with traditional contracts, token-based compensation may enlarge the supply elasticity and thereby reduce θ by alleviating the problem of limited commitment as previously discussed.

Lemma 1 (**Parameterized Optimal Investment**). *Under the parametric restriction given by Equation (20), the platform's optimal investment is*

$$L_t^* = \frac{V_{A_t}\mu^H + \frac{V_{M_t}}{P_t}}{-\frac{V_{M_t}}{P_t}\theta - V_{A_tA_t}A_t\sigma^2}, \tag{21}$$

To obtain closed-form solutions, we assume that u_i follows the commonly used Pareto distribution on $[\underline{U}_t, +\infty)$ with cumulative probability function (c.d.f.) given by

$$G_t(u) = 1 - \left(\frac{\underline{U}_t}{u}\right)^{\xi}, \tag{22}$$

where $\xi \in (1, 1/\gamma)$ and $\underline{U}_t = 1/(\omega A_t^{\kappa}), \omega > 0, \kappa \in (0,1)$. The cross-section mean of u_i is $\frac{\xi \underline{U}_t}{\xi - 1}$.

Note that $\underline{U}_t$ decreases in A_t, which reflects the competition from alternative platforms that are inspired by the platform's success (i.e., a high value of A_t). For example, this specification captures the reality that after the success of Bitcoin, alternative blockchains emerge as competitors in the area of payments. Similarly, there now exist alternative platforms to Ethereum for smart contracting. The effects of competition are small when ω is close to zero. As A_t increases, the mass of u_i is shifted towards lower values.[22]

Lemma 2 (**Parameterized User Base**). *Given A_t and μ_t^P, from Proposition 2, we have a unique non-degenerate solution, N_t, for Equations (15) and (16) under the Pareto distribution of u_i given by Equation (22):*

$$N_t = \left(\frac{A_t^{1-\kappa}\alpha}{\omega\phi}\right)^{\frac{\xi}{1-\xi\gamma}} \left(\frac{1-\alpha}{r-\mu_t^P}\right)^{\left(\frac{\xi}{1-\xi\gamma}\right)\left(\frac{1-\alpha}{\alpha}\right)}, \tag{23}$$

if $\underline{u}_t \geq \frac{1}{\omega A_t^{\kappa}}$*, i.e.,* $A_t^{1-\kappa}\left(\frac{1-\alpha}{r-\mu_t^P}\right)^{\frac{1-\alpha}{\alpha}} \leq \frac{\omega\phi}{\alpha}$*; otherwise,* $N_t = 1$.

Our later discussion focuses on $\xi\gamma < 1$ so that the user base, N_t, is increasing in the platform productivity in spite of platform competition. This is realistic because a technology leader usually benefits from its innovation despite the presence of potential competing

[22]Platform competition can also be captured by the depreciation of A_t. The current specification lends technical convenience.

followers. Moreover, we focus on low values of A_t such that $N_t < 1$ in the Markov equilibrium so as to examine how token allocation interacts with user base dynamics. Under the Pareto distribution, the aggregate transaction need is given by

$$U_t = N_t \left(\frac{\xi \underline{u}_t}{\xi - 1} \right) = \left(\frac{\xi}{(\xi - 1)\, \omega A_t^{\kappa}} \right) \left(\frac{A_t^{1-\kappa} \alpha}{\omega \phi} \right)^{\frac{\xi - 1}{1 - \xi\gamma}} \left(\frac{1 - \alpha}{r - \mu_t^P} \right)^{\left(\frac{\xi-1}{1-\xi\gamma}\right)\left(\frac{1-\alpha}{\alpha}\right)}. \quad (24)$$

We adopt the following parameter restriction, which helps reduce the dimension of state space in our numerical analysis and convey economic intuitions.

Assumption 1. $\frac{2\xi - 1}{1 - \xi\gamma} = \frac{\kappa}{1-\kappa}$.

The assumption implies $\kappa > 1/2$ given that $\gamma > 0$ and $\xi\gamma < 1$. Moreover, N_t increases in A_t while U_t decreases in A_t, and the effects of A_t on N_t and U_t exactly cancel out each other in the token pricing formula (Equation (19)). The intuition is that even though higher platform productivity induces more users to adopt, individual users' needs are now weaker because they have access to alternative platforms. The token pricing formula then simplifies.

Lemma 3 (**Parameterized Token Price**). *Under Assumption 1, the equilibrium token price in Proposition 3 when $N_t < 1$ is given by*

$$P_t = \frac{A_t}{M_t} \frac{\xi}{(\xi - 1)\, \omega^{\frac{1}{1-\kappa}}} \left(\frac{\alpha}{\phi} \right)^{\frac{\kappa}{1-\kappa}} \left(\frac{1-\alpha}{r - \mu_t^P} \right)^{\frac{1}{\alpha} + \left(\frac{1-\alpha}{\alpha}\right)\left(\frac{\kappa}{1-\kappa}\right)}. \quad (25)$$

In the following, we characterize a Markov equilibrium in a transformed state space. The equilibrium variables depend on (m_t, A_t), where

$$m_t = \frac{M_t}{A_t}. \quad (26)$$

By inspecting Equation (25), we can see that m_t is the only state variable driving the token price – in such an equilibrium μ_t^P is a function of m_t only and so is P_t.

For the parameters that affect user activities, we follow CLW to set $\alpha = 0.3$, $\phi = 1$, $r = 0.05$, and the volatility parameter, $\sigma^H = 2$. For the mean productivity growth, we set $\mu^H = 0.5$, which generates a μ_t^P in line with the values in CLW. We set the rest of parameters to illustrate the qualitative implications of the model: $\theta = 10,000$ so the highest level of investment, L_t, is about 25% higher than the lowest level for illustrative purpose; $\xi = 2$, $\kappa = 0.8$ and $\omega = 100$ for the distribution parameters of u_i; $\chi = 20\%$ for the financing cost.

The model's qualitative implications are robust to the choice of these parameters. Finally, we set $\gamma = 1/8$ to satisfy Assumption 1.

4.2 Solving the Equilibrium

We numerically solve the model in the space (m_t, A_t), where $m_t = M_t/A_t$, instead of the original space (M_t, A_t), because given the parametric choices in Section 4.1, m_t shall be the only state variable driving the token price P_t and the platform investment L_t. By Itô's Lemma, the dynamics of m_t is given by:

$$\frac{dm_t}{m_t} = \frac{dM_t}{M_t} - \frac{dA_t}{A_t} + L_t^2(\sigma^H)^2 dt, \tag{27}$$

where the last term is a quadratic variation term from Itô's calculus. We conjecture that the value function $V(M_t, A_t) = v\left(\frac{M_t}{A_t}\right) A_t$, so the derivatives are given by:

$$V_{M_t} = v'(m_t), \quad V_{A_t} = v(m_t) - v'(m_t)\, m_t, \quad V_{A_t A_t} = v''(m_t)\, \frac{m_t^2}{A_t}. \tag{28}$$

In the interior region ($dD_t = 0$), the HJB equation is:

$$rv(m_t) = \max_{L_t} v'(m_t) \frac{\left(L_t + \frac{\theta}{2} L_t^2\right)}{P_t} + \left[v(m_t) - v'(m_t)\, m_t\right] L_t \mu^H + \frac{1}{2} v''(m_t)\, m_t^2 L_t^2 (\sigma^H)^2. \tag{29}$$

To confirm the value function conjecture, we should show P_t and L_t are functions of m_t.

Substituting these derivatives of $V(M_t, A_t)$ into the optimal investment, we have:

$$L_t^* = \frac{\left[v(m_t) - v'(m_t)\, m_t\right] \mu^H + \frac{v'(m_t)}{P_t}}{-\frac{v'(m_t)}{P_t}\theta - v''(m_t)\, m_t^2 \left(\sigma^H\right)^2}. \tag{30}$$

Therefore, L_t is a function of m_t as long as P_t is a function of m_t. Equation (25) implies that P_t is a function of m_t because when P_t is a function of m_t, so is μ_t^P. Hence the conjecture of m_t being the only the state variable driving P_t and L_t is internally consistent.

The optimality conditions for dD_t give us the boundary conditions for solving $v(m_t)$. We conjecture that $v' < 0$ because when m_t increases, more tokens are supplied and the current and future token prices decline, which reduces the owner's continuation value. There exists a lower bound for m_t such that $m_t \geq \underline{m}$, $dD_t^* \geq 0$. At this payout boundary, the marginal value of retained token must be equal to the market value, i.e.,

$$-v'(\underline{m}) = P(\underline{m}). \tag{31}$$

Since the payout boundary is optimally chosen, we also have the usual "super contact" condition:

$$-v''(\underline{m}) = P'(\underline{m}). \tag{32}$$

Moreover, because the payout boundary is a reflecting boundary, to rule out arbitrage in the token market, we have:

$$P'(\underline{m}) = 0. \tag{33}$$

Intuitively, the distribution of token dividends happens when the token supply is sufficiently small relative to the platform productivity, i.e., low m_t.

The upper bound for m_t is the buyback boundary. As m_t increases, the token supply is large relative to the platform productivity, and the token price declines, so the owners buy back and burn tokens out of circulation. At $m_t = \overline{m}$,

$$-v'(\overline{m}) = P(\overline{m})(1+\chi). \tag{34}$$

Since the buyback boundary is optimally chosen, we also have the "super contact" condition:

$$-v''(\overline{m}) = P'(\overline{m})(1+\chi). \tag{35}$$

Moreover, because the payout boundary is a reflecting boundary, to rule out arbitrage in the token market, we have:

$$P'(\overline{m}) = 0. \tag{36}$$

At the boundaries, the amount of payout and buyback exactly offsets the variation in m_t from L_t and the shock dZ_t that would otherwise drive it beyond the boundaries.

Proposition 4 (**Markov Equilibrium**). *With Lemmas 1, 2, and 3, there exists a Markov equilibrium with A_t and $m_t = M_t/A_t$ as state variables and the following properties:*
(i) $P(m_t)$ and $v(m_t)$ uniquely solve the system of ordinary differential equations given by Equation (25) and (29) subject to boundary conditions given by Equations (31) to (36).
(ii) Platform investment L_t and the payout/buy-back policy D_t all depend on m_t only.
(iii) Users' optimal token holdings and participation decisions together with the user base

depend on both m_t and A_t according to Proposition 2.

Discussion: token supply limit. Blockchain platforms often feature a maximum total token supply. One way to incorporate this is to have an absorbing upper bound of m_t, say $\widetilde{m}$. In such case, once reaching a multiple of the platform productivity, i.e., $\widetilde{m}A_t$, the supply would grow proportionally with A_t forever, and according to Lemma 3, token price will then be a constant. As for newly issued tokens, they are divided between the entrepreneur and contributors, and here the entrepreneur faces a standard consumption-savings trade-off – if she takes a larger share of the new tokens, the productivity grows slower.

4.3 Endogenous Platform Development

Panel A of Figure 2 plots $v(m_t)$. Because the value function, $V(M_t, A_t) = v(m_t) A_t$, Panel A shows that the platform owners' value, scaled by productivity, declines in the productivity-adjusted token supply (a form of platform "inflation"). Intuitively, when more tokens are circulating relative to platform productivity, it is more likely for the owner to reach the buyback (upper) boundary and pay the financing cost, and in the less likely event of token payout, the owner receives a lower value due to the depressed token price when m_t is high. Note that the value function is always positive in Panel A, suggesting that the platform owner never abandons the platform. The curve starts at the payout boundary and ends at the buyback boundary where the owner actively devotes real resources to buy back and burn tokens out of circulation in order to support token price and her franchise value.

Panel B of Figure 2 plots the optimal platform investment against the productivity-adjusted token supply. The declining pattern is largely driven by the rising cost of token issuance (Panel C), even though as m_t increases, the marginal value of productivity enhancement rises (Panel D). The economic force of token overhang dominates.

The optimal L_t^* decreases in $-V_{M_t}/P_t$, the ratio of the marginal cost of token issuance, $-V_{M_t}$, to the token market price, P_t. This ratio measures the valuation gap that exists between platform owners (insiders) and the workers and users (outsiders), i.e., the token issuance cost. When the gap is high, it is costly from the owners' perspective to gather resources using tokens. The ratio starts at one, as implied by the value-matching condition of the payout boundary. The gap widens as the token supply outpaces the growth of platform productivity, i.e., as m_t increases, and eventually, when the gap reaches $(1+\chi)$, the platform owner's optimal buy back tokens. The increasing $-V_{M_t}/P_t$ largely contributes to

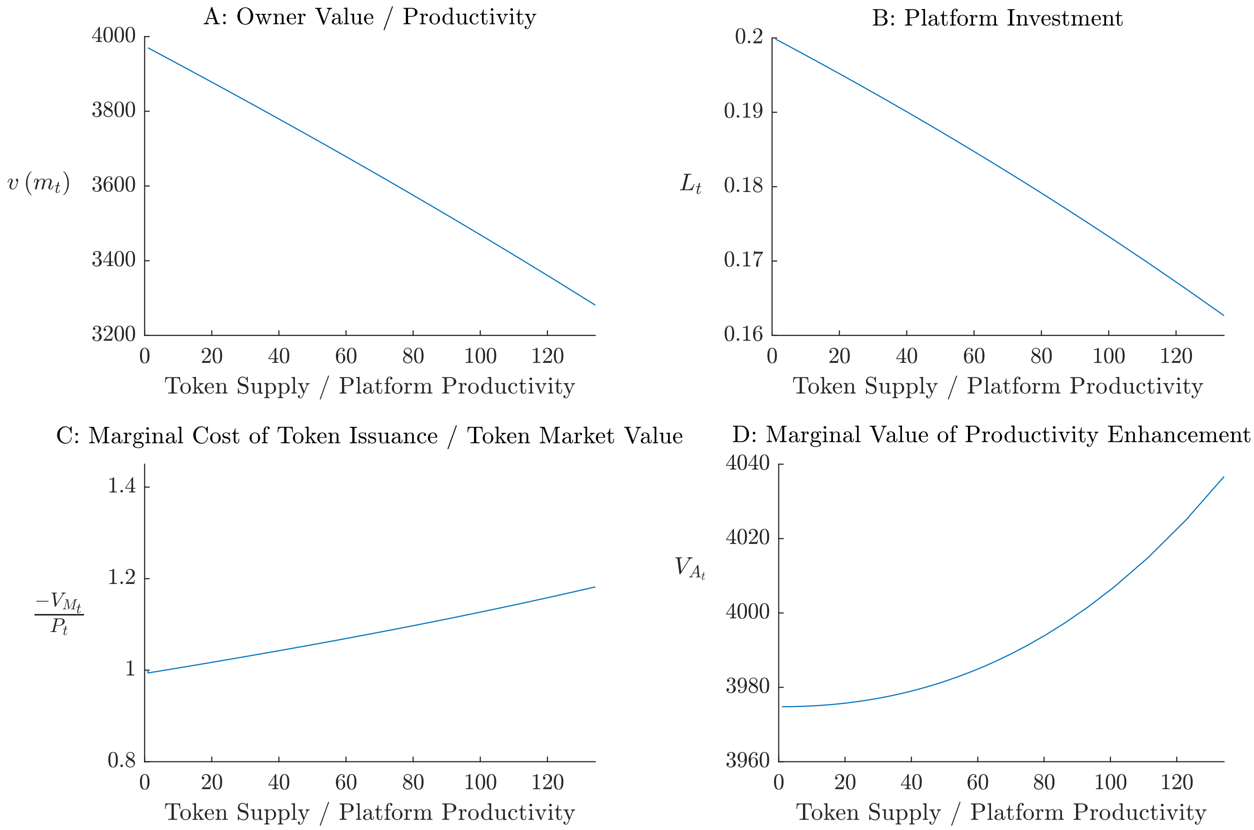

Figure 2: **Optimal Platform Investment Financed by Token Issuances**.

the decreasing pattern of L_t^*.

The optimal L_t^* increases in V_{A_t}, the marginal value of A_t, because on average, investment has a positive productivity, i.e., $\mu^H > 0$, more resources gather by token payments, L_t, means a higher expected growth of A_t. Near the buyback boundary, V_{A_t} is high because an increase of A_t reduces m_t and the likelihood of costly buyback.

Finally, according to Equation (10), the second-order derivative of the value function with respect to productivity also affects the choice of investment, which essentially represents a precautionary motive in the choice of L_t. It is not presented here because under the current parameterization, its quantitative contribution to the dynamics of L_t is small. However, the intuition of precaution towards investment risk is still interesting. The token distribution is largely a real-option decision. While it is not completely irreversible, reversing it (i.e., buying back tokens) incurs a cost of χ.[23] The probability of incurring such costs increases

[23]Fpr example, the Synereo team has to hold multiple meetings and incur effort cost to explain to users when the team burned 33% of its cryptocurrency reserves. https://synereo.com/burn-amps/

as m_t approaches the buyback boundary, so the platform becomes increasingly cautious on making large investment that also brings in large exposure to investment productivity shock in Equation (2). Therefore, the platform owner may choose to invest less in order to preserve some slack, i,e., the flexibility to issue more tokens in the future.

Overall, our model reveals a rich set of trade-offs in the choice of token-compensated contributions for platform development. The model has the potential to explain various features of token distribution to open-source engineers, miners (ledger maintainers), and crowd-sourced financiers in practice.

4.4 Token Price and User Adoption

The dynamics of token price is directly linked to that of token supply. As shown in Panel A of Figure 3, the token price, P_t, declines in m_t, the productivity-adjusted token supply. From Equation (27), the diffusion of m_t is $-m_t L_t^* \sigma^H$ (through $-dA_t/A_t$), which is negative. Therefore, a positive shock in labor productivity decreases m_t by increasing A_t, moving the economy closer to the payout boundary. The token price increases in response and is procyclical with respect to the shock.

That said, in stark contrast to the 200% per annum volatility of labor productivity that we input, i.e., the fundamental volatility, σ_t^P is surprisingly small (below 0.2% in Panel B of Figure 3) due to the stabilizing effect of the endogenous cumulative token process D_t. The platform owners' incentive to pay out when m_t is low and buy back when m_t is high moderate the variation of token price through the control over token supply.

Corollary 2. *From Proposition 1, the token price is bounded in* $\left[-\left(\frac{1}{1+\chi}\right) V_{M_t}, -V_{M_t}\right]$.

Here the token value has two anchors. First, users need tokens for transactions. Second, when token price declines significantly below the marginal cost of having one more unit of token circulating, i.e., $P_t \leq -V_{M_t}/(1+\chi)$, the owner *optimally* chooses to exchange real resources (i.e., dollars) for tokens to reduce the supply.

Panel C of Figure 3 shows the expected token price change against m_t. When m_t is low, the expectation is negative, reflecting the likely token-supply increase due to payout and labor demand (Panel A of Figure 2). The expected token price change gradually increases and eventually becomes positive because the expected token-supply *change* is increasingly dominated by the declining investment (Panel A of Figure 2) and the possibility of token buyback by the platform owners.

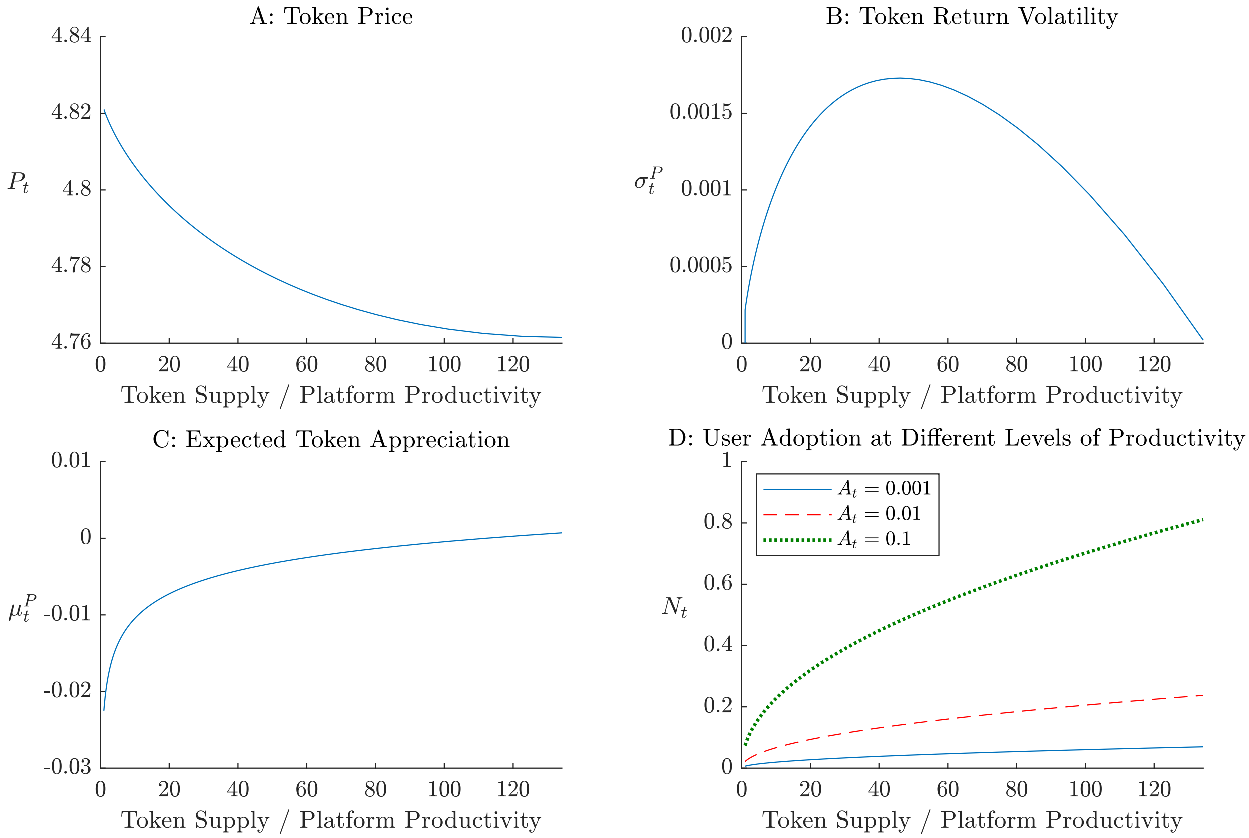

Figure 3: **Token Price Dynamics, Stablecoin, and User Adoption**.

In Proposition 2, unlike other variables in the model that only depends on m_t, the user base N_t depends on both m_t (through μ_t^P) and A_t. Panel D of Figure 3 plots the user base dynamics with different values of A_t to show that as the the risk-adjusted token appreciation, μ_t^P, increases, the user base also increases.

Discussion: stablecoins. Although price volatility does not necessarily invalidate the medium-of-exchange function of tokens (Schilling and Uhlig, 2018), achieving stable values has become a holy grail in the cryptocurrency industry. Practitioners have proposed several candidate designs for stablecoins as a powerful alternative to fiat money and even digital payments through the commercial banking system (e.g., Duffie, 2019).

A popular approach is to mimic open market operations done by central banks. When token price is low, the platform issues token bonds to buy back tokens. Token bonds promise to pay the principal with interest in the future, but all payments are in tokens. The problem with this design is that an inter-temporal substitution between current and future tokens tilts the schedule of token supply over time, but it does not introduce any real resource to support token price, nor does it provide any incentive to economic agents to devote such resources. A champion of this design, the Basis stablecoin project that attracted $133 million of venture capital in April 2017, has closed down all operations, citing US securities regulation as the reason for its decision.[24]

An alternative design is collateralization, backing token value with real resources such as dollar (e.g., Tether, Circle, Gemini, JPM coin, and Paxos), oil reserves (e.g., Venezuelas El Petro, OilCoin, and PetroDollars). A derivative of such design is to further tranche the claims on real resources, so tokens as means of payment are the most senior tranche, which is less information-sensitive and thus has a stable secondary-market value. Such designs are often subject to frauds and market manipulations (e.g., Griffin and Shams, 2018).

The way the buyback policy stabilizes token value in our paper differs from these existing proposals. First, we introduce the value of platform ownership — the continuation or franchise value — that derives value from token dividends which are optimally chosen. Then, given the economic cost of buying back tokens, χ, we characterize the incentive for the platform owners to voluntarily buy back tokens using the numeraire goods (real resources). The parameter χ may change, and can even be a function of macroeconomic state variables to better represent the cost of token buyback.

Note that it is in the interest of platform owners such as the founders to buy back tokens, which provides an incentive-compatible support for token price. Later we introduce commitment using smart contracting which can further help creating stablecoins.

5 Blockchain and the Value of Commitment

The rise of tokens as means of payment on digital platforms is a recent phenomenon with many applications inspired by the success of Bitcoin, Ethereum, and other blockchain-based startups. So far, we have focused on discretionary token-supply policies of the platform – depending on the state of the world, platform owners can freely adjust the token issuance to finance platform development or to pay the themselves or to buy back tokens.

The blockchain technology allows consensus protocols and token supply rules to be immutable. Next, we study how commitment to predetermined token-supply rules addes value. Our analysis sheds light on why tokens become a viable payment solution after the blockchain

[24] https://icoexaminer.com/ico-news/133-million-basis-stablecoin-project-ceases-and-desists-citing-regulatory-concerns/

technology becomes available and the welfare gains for platform owners and users. In Appendix B, we summarize the three aspects of blockchain technology that are critical in enabling commitment, including data structure, smart contracting, decentralized data storage and governance. We highlight both the advantages of blockchain-based commitment over traditional approaches (e.g., collateral) and its limitations.

Constant growth of token supply. To illustrate the impact of commitment brought forth by the blockchain technology, we consider a specific case in which $F(L_t, A_t)/P_t dt = \mu^M M_t dt$, which implies a constant growth of token supply in the interior region ($dD_t = 0$) to finance the enhancement of platform productivity:

$$dM_t = F(L_t, A_t)/P_t dt = \mu^M M_t dt, \tag{37}$$

which is popular among blockchain applications as a way to create scarcity and avoid inflation of tokens.[25] This rule of token supply implies that the resources a platform gathers, L_t, is fixed given the current productivity A_t, token price P_t, and token supply M_t. In our numerical solution, we use $\mu^M = 10$, which is the average level of token growth in the baseline model.

We still allow the platform owners to receive token dividends and buy back tokens, but with L_t fixed, the owners' only control variable is dD_t and the HJB equation directly specifies a differential equation for the value function:

$$\begin{aligned} rV(M_t, A_t)\, dt = & \max_{dD_t} P_t dD_t \left[\mathbb{I}_{\{dD_t \geq 0\}} + (1+\chi)\,\mathbb{I}_{\{dD_t < 0\}}\right] + V_{M_t}\left[\mu^M M_t dt + dD_t\right] \\ & + V_{A_t} A_t L_t \mu^H dt + \frac{1}{2} V_{A_t A_t} A_t^2 L_t^2 (\sigma^H)^2 dt. \end{aligned} \tag{38}$$

Comparing it with Equation (9), the token paid for L_t is replaced by $\mu^M M_t dt$. Under the parametric choices in Section 4.1 and in the interior where $dD_t = 0$, we have

$$rv(m_t) = v'(m_t)\, m_t \mu^M + \left[v(m_t) - v'(m_t)\, m_t\right] L_t \mu^H + \frac{1}{2} v''(m_t)\, m_t^2 L_t^2 (\sigma^H)^2, \tag{39}$$

[25] Blockchains often feature supply increments commensurate with the platform productivity change. Ethereum has roughly fixed increments while Bitcoin's minting rate is a constant that halves as the system matures via a longer transaction chain (specifically, every 210,000 more blocks). Because we model platform productivity as driven by geometric Brownian shocks in investment efficiency and contribution payment $F(L_t, A_t)$ is linear in At, the constant growth of token supply is the natural analogy with the practice.

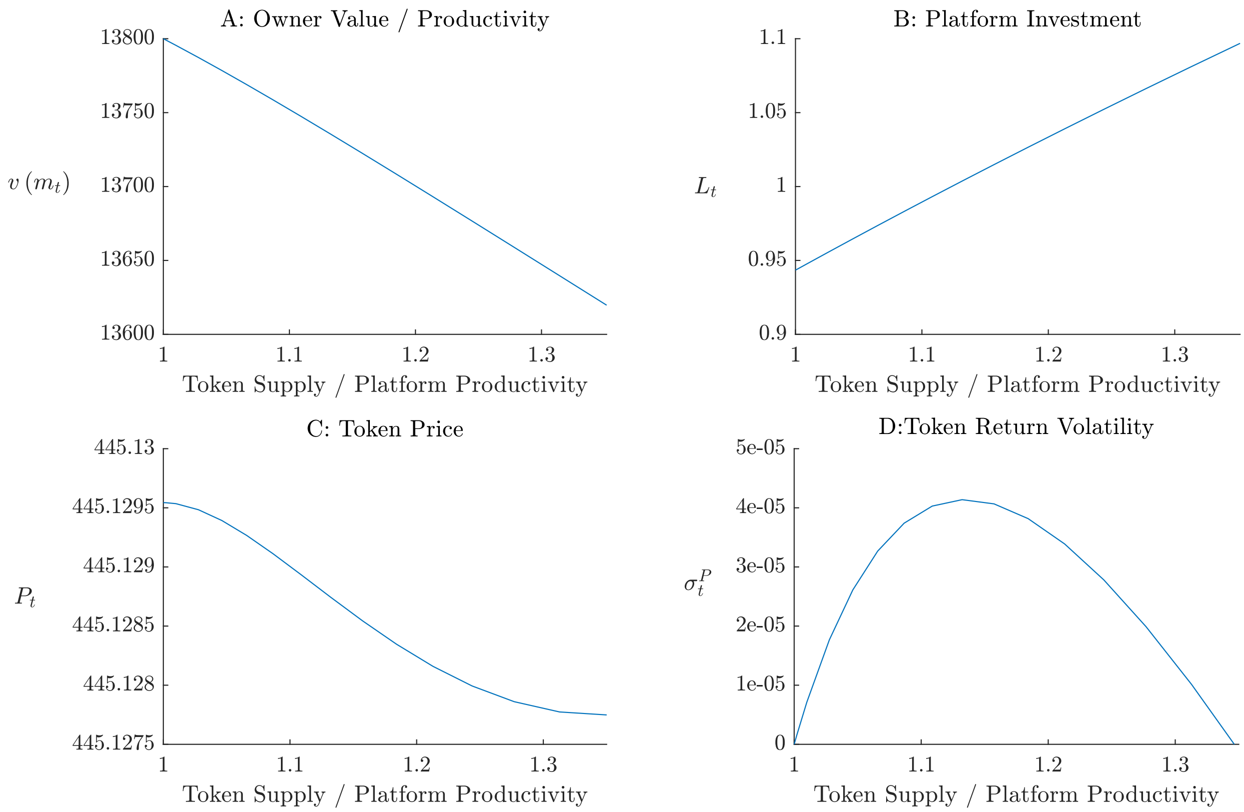

Figure 4: **Constant Growth of Token Supply for Platform Development**.

where L_t is given by

$$L_t + \frac{\theta}{2} L_t^2 = \mu^M P_t m_t. \tag{40}$$

The boundary conditions are the same as those of the baseline model. Because the left-hand side increases when $L_t > -1/\theta$ and $L_t \geq 0$, platform investment increases in P_t and m_t. Intuitively, when tokens are more valuable, the platform gathers more decentralized contributions; when the token supply is high, the amount of newly issued tokens is also high per unit of time, leading to a larger payment for L_t.

Proposition 5 (Predetermined Token Growth). *Under the commitment to constant growth of token supply for productivity enhancement, platform investment given by Equation (40) increases in $P_t m_t$. The owner receives token dividends ($dD_t^* > 0$) only if $P_t \geq -V_{M_t}$, and buys back and burns tokens out of circulation ($dD_t^* < 0$) only if $-V_{M_t} \geq P_t(1+\chi)$. Token price is determined by Equation (19) as in the baseline model.*

Figure 4 plots the key variables from the solution under the commitment of token growth. Comparing Panel A of Figure 4 with Panel A of Figure 2, we can see that commitment significantly increases the platform owners' value. By comparing Panel B in the two figures, we see that such an increase mainly comes from an about five times larger level of investment. Therefore, commitment to token supply policy mitigates the problem of under-investment under token overhang.

Commitment adds value because the financing costs χ creates a conflict of interest between the platform owner and users, which manifests itself when we examine the usage value and the investment value of tokens. To the owner, the value of tokens is $-V_{M_t}$, while to the users, it is P_t. The wedge between $-V_{M_t}$ and P_t widens as the productivity-adjusted token supply, m_t, increases and reaches χ at the buyback boundary. Therefore, as shown in Equation (10), the financing cost translates into a dynamic cost of token issuance to contributors that discourages investment. Intuitively, under-investment occurs because the platform owner fully bears this dynamic token issuance cost, $-V_{M_t}/P_t > 1$, yet the resulting productivity enhancement benefits both the owners (by decreasing m_t and thus increasing $v(m_t)$) and the users (via the token usage value — a larger flow of convenience yield). Moreover, at the buyback boundary, the platform owner bears χ while the token buyback benefits both the owner (also by decreasing m_t and increasing $v(m_t)$) and the users (through the token investment value — the resulting token appreciation).

Commitment mitigates the under-investment problem. With commitment, the constant growth of token supply in the interior region isolates investment from the influence of financing cost. As a result, investment depends directly on the state variable m_t as shown in Equation (40). When m_t increases, the declining token price (Panel C of Figure 4) drives down L_t but the increasing token supply drives up L_t. In Panel B of Figure 4, the latter force dominates, so the larger m_t is, the higher platform investment, exhibiting a pattern of investment opposite to that in the baseline model (Panel B of Figure 2).

Commitment also creates more frequent token buyback. The range of m_t in Figure 4 is reduced by one hundred times in comparison with that in Figure 2 and 3. In other words, the platform owner is more willing to buy back and burn tokens at a much lower threshold level of productivity-adjusted token supply. As m_t increases, the ratio of owner's token value, $-V_{M_t}$, to users' token value, P_t, increases and reaches $1+\chi$ at the buyback boundary. A tighter range of m_t suggests that the ratio rises faster in m_t under commitment. When investment increases in m_t, an increasing amount of tokens are issued at the expense of platform owner to boost productivity that benefits users. Therefore, as m_t increases, the divergence of owner's and users' interest, $-V_{M_t}/P_t$, becomes increasingly large, reaching $1+\chi$ fast and justifying token buyback at a low level of m_t.

Even though the platform owner ends up paying more frequently the financing cost χ under commitment, the owner's value is higher than the discretionary case because the higher level of platform investment translates into a higher token value through users' expectation of productivity growth. The value added from commitment is analogous to that in other settings of corporate finance. For example, firms' ability to commit to future capital-structure choices improves the firm's value (Demarzo, 2019). By demonstrating the role of commitment in mitigating the under-investment problem of using tokens, our model helps rationalize the explosive growth of token usage after the advent of blockchain technology.

Stablecoins under commitment. Many blockchain applications aim for creating tokens with stable value so that tokens may perform the roles of both means of payment and unit of account. From a theoretical perspective, there are various merits to a unit of account whose value is stable (e.g., Doepke and Schneider, 2017). A rigid token supply rule is often considered as a contributing factor to price volatility because volatile demands directly translate into price fluctuations. However, as shown in Panel D of 4, the annual volatility of token return, dP_t/P_t, is less than one basis point in spite of the 200% annual volatility of productivity shock. The commitment to constant token growth thus brings further stability on top of the volatility reduction that we see in the baseline model (Figure 3).[26]

The intuition is straightforward. Because commitment increases the sensitivity of $-V_{M_t}/P_t$ to m_t, buyback happens at a low threshold level of productivity-adjusted token supply. As shown in the baseline model, token buyback reduces the token volatility. When the owner buys back tokens more frequently under commitment, volatility is reduced accordingly.

The commitment to constant token growth brought by blockchain technology not only achieves stability of token price but also simplifies the protocol design. Moreover, since the platform investment increases in the token market capitalization (Equation (40)), the expected growth of platform productivity is relatively easy to calculate. In other words, under commitment, there exists an one-to-one mapping between token market capitalization and the enhancement of platform productivity, suggesting a simple way to rank token-based platforms by their quality.

[26]If the end goal is price stability, one can even trivially achieve perfect stability by committing to have $M_t = A_t$ always, because then the driver for price dynamics, m_t, becomes a constant. Here our analysis is motivated by the tokens with constant growth rate of supply, for example, Ether.

6 Conclusion

We develop a dynamic model of platform economy, where tokens are used as means of payment among users and issued by the platform to finance its growth. Tokens facilitate user transactions and compensate distributed ledger-keepers, open-source developers, and crowdfunders for their contributions to platform development. Platform owners maximize their seigniorage by managing token supply, subject to the conditions that users optimally decide on token demand and rationally form expectation of token price dynamics.

We characterize the optimal token-supply strategy and its implications on user-base dynamics, endogenous platform growth, and token price dynamics. A key mechanism is the wedge between insiders' (entrepreneurs') token valuation and that of outsiders (users and workers) – when the valuation wedge falls to zero, the platform owners optimally issue token dividends to themselves; when it rises to an endogenously determined threshold, they optimally burn tokens out of circulation to stabilize token value. The wedge creates under-investment in platform productivity. As commitment devices, blockchains enable rule-based token supply, and thereby, overcome platform owners' time inconsistency to mitigate under-investment. We also discuss important implications of optimal dynamic token allocation for token price, user adoption, stablecoins, among other issues.

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Appendix A - A Model of Platform Transaction Surplus

We adopt the following theoretical foundation for the specification of platform transaction surplus from CLW. Time, $t \in \mathbb{R}_+$, is continuous. The economy is populated with a unit measure of infinitely lived risk-neutral agents who have a discount rate $r > 0$. Agents have investment opportunities that occur at Poisson arrival times, $\{T_n\}_{n=1}^{+\infty}$, with time-varying and agent-specific intensity, $\lambda_{i,t}$. At a Poisson time, T_n, agent i is endowed with a technology, $\omega_i F(\cdot)$, that transforms labor into goods, and is matched with another agent who can supply the labor input. Agent-specific productivity is captured by ω_i. To simplify the exposition, we assume that the labor supply has a constant marginal cost of one, and the supplier breaks even, so the trade surplus accrues to agent i.

Agent i's labor demand, denoted by h, is not restricted by the real balance of token holdings, $P_t k_{i,T_n-}$, where k_{i,T_n-} denotes the units of tokens carried to T_n. Since the focus of this paper is not on financial constraints, we allow the agent to borrow dollars (an instantaneous loan) at zero cost, so h may exceed agent i's wealth at the moment. Once the production is complete, the loan is repaid immediately by the goods produced.

The lumpy payment for labor incurs a transaction cost that is proportional to the total payment value, δh ($\delta > 0$), but using tokens as means of payment save the transaction cost by $U(P_t k_{i,T_n-})$ ($U' > 0$, $U'' < 0$) because agent i does not need to exchange dollars for tokens, the required means of payment on the platform. This transaction cost can be interpreted as the cost of traditional bank transfer service, legal costs of contracting. Native tokens in many cases allow transaction parties unknown and untrusted to still complete a value transfer remotely, or to contract on simple terms, thanks to the blockchain ledger and smarting contracting functionalities. For these reasons, platforms such as Kin require all on-platform transactions to be mediated using Kin tokens.

Agent i maximizes the investment profit, which is a jump in wealth,

$$\max_{h} \omega_i F(h) - h - (\delta h - U(P_t k_{i,T_n-})), \tag{41}$$

where the last term is the transaction cost. The optimal labor demand, h^*, is given by

$$\omega_i F'(h^*) = 1 + \delta, \tag{42}$$

so that the marginal value of production is equal to the marginal cost of labor plus the transaction cost, δ. We can substitute the constant h^* into the investment profit to have

$$\omega_i F(h^*) - (1+\delta) h^* + U(P_t k_{i,T_n -}). \tag{43}$$

We assume that ω_i is sufficiently high so $h^* \geq P_t k_{i,T_n -}$. The conversion between the local currency (token) and other assets can be costly, especially when a lumpy transaction is required within a short period of time. By holding tokens, agents save such costs.

Therefore, at time t, agent i has an expected gain of $\lambda_{i,t} U(P_t k_{i,t}) dt$ by holding $k_{i,t}$ units of tokens for dt. To obtain a tighter analytical characterization of the equilibrium, we specify $\lambda_{i,t} = (N_t^\gamma A_t e^{u_i})^\alpha$ ($\alpha \in (0,1)$). A larger community (N_t) makes it easier to find transaction counterparties. A higher platform quality (A_t) makes matching more efficient. And u_i captures agent-specific transaction needs. We specify $U(P_t k_{i,t}) = \chi (P_t k_{i,t})^{1-\alpha}$, so the expected transaction costs saved are

$$\lambda_{i,t} U(P_t k_{i,t}) = (N_t^\gamma A_t e^{u_i})^\alpha (P_t k_{i,t})^{1-\alpha} \chi dt. \tag{44}$$

We normalize $\chi = 1$ because its scaling effect can be subsumed by the level of A_t.

We may reinterpret h as goods or services other than labor, and the investment profit as a burst of consumption or utility value from transactions. The features our micro-foundation captures are two-fold: (i) the arrival of transaction opportunities depends on the user base, the platform quality, and agent-specific factors; (ii) holding tokens on the tokenized platform saves transaction costs for lumpy payments. In essence, we model the flow utility of token holdings as a form of convenience yield, as emphasized by John Cochrane.[27]

We have many applications of native tokens as means of payment on platforms. In the case of Kin, entrepreneurs obtain information from consumer surveys that helps improve product quality. Consumers are rewarded by the native currency, Kin tokens. In our model, we do not differentiate buyers and sellers among users because in reality, entrepreneurs and service providers are often consumers of other sellers' products in the platform market place. They can simultaneously take on different roles (investor, user, developer or operator), and actively participate in a sharing economy.

[27]Please refer to https://johnhcochrane.blogspot.com/2017/11/bitcoin-and-bubbles.html

Appendix B - Institutional Background

This section provides the institutional background of token-based platforms. We discuss how platforms, blockchains, and the use of tokens are all connected in practice, using the Kik/Kin system and various other real-life examples. First, the platform token plays dual roles – it serves as local means of payment among users, and as a platform financing tool (contributors' compensation), it gathers efforts and resources for platform development. Second, platform designers (owners and entrepreneurs) increasingly utilize token-supply strategies to manage platform development dynamically, and derive benefits by issuing tokens to themselves and actively managing the total amount of tokens in circulation. We highlight that, on traditional and blockchain-based platforms, platform owners exercise significant discretion in dynamic token allocation, which is a salient feature of our baseline model. Finally, we discuss how blockchain technology can limit discretion and enable commitment.

To start, we note that in the past few years, over 1000 cryptocurrencies have been introduced on digital platforms. In these applications including Bitcoin and Ripple, blockchains provide decentralized consensus that helps avoid double-spending and enables digital currencies to act as media of exchange among platform users. In terms of (crowd-based) financing, blockchain-based crypto tokens have also emerged as a popular means to raise funds for startups (e.g., Howell, Niessner, and Yermack, 2018; Davydiuk, Gupta, and Rosen, 2019). In Initial Coin Offerings (ICOs), Security Token Offerings (STOs), and Initial Exchange Offerings (IEOs), entrepreneurs sell "tokens" or "AppCoins" to dispersed investors around the globe.[28] Moreover, tokens are routinely used as compensation for talents joining the startup teams. Kik/Kin constitutes a well-known example.

Kik/Kin case. Kik Interative Inc. is a social media messaging company founded in Waterloo in 2009 and is currently under a well-publicized lawsuit by the SEC for violations of the Securities Act. Kik introduced a messaging app "Kik Messenger" in 2010 that later became one of the most popular social media applications (Brenner, 2018).

To better compete with larger players in the advertising market and to allow its users monetize their participation, Kik launched Kik Points, a virtual currency within Kik Mes-

[28]While the first ICO in 2013 raised a meager \$500k and sporadic activities over the next two years. 2016 saw 46 ICOs raising about \$100m and according to CoinSchedule, in 2017 there were 235 Initial Coin Offerings. The year-end totals came in over \$3 billion raised in ICO. In August, 2017, OmiseGO (OMG) and Qtum passed a US\$1 billion market cap today, according to coinmarketcap.com, to become the first ERC20 tokens built on the Ethereum network and sold via an ICO to reach the unicorn status.

senger in 2014. Advertisers can exchange fiat money with Kik for points to pay consumers for answering surveys and polls and consumers can pay for purchases and usage with the points. Kik Points while in operation created an average of 300,000 daily transactions, but advertisers and users are concerned that nothing prevents Kik from creating more Kik Points or not accepting them entirely in future.

The company therefore conceived towards the end of 2016 a new blockchain-based platform, Kin, which issues native tokens for user transactions and compensations for dispersed contributors in an ecosystem for digital services and social network wherein Kik is a key founding member.[29] The Kin project is overseen by the Kin foundation and aims to offer Kik and similar developers a way to monetize their businesses which was previously difficult without a large initial scale or potentially abusing user data. The blockchain-based token can credibly have a limited supply. Moreover, token demand can be boosted by token usage not only on Kik Messenger but also for potentially unlimited number of applications, services, products offered by participating developers. Therefore, Kin has the potential to overcome the concern of over supply and value destruction.

Importantly, even though the maximum supply of Kin is at $10 trillion USD, the founding team and the Kin Foundation actively manage the dynamic token allocations (e.g., using smart contracts): 30% is pre-allocated to the original Kik platform for being a founding member of Kin and early adopter, 10% (1 trillion) of Kin tokens are issued to dispersed investors in a 2-week initial coin offering (ICO) in 2017, raising about US$100 million, 60% is initially allocated to the Kin foundation and is to be gradually distributed to early users and contributors through the Kin Rewards Engine schema or used to cover operation and marketing expenses. Every year, 20% of the remaining token reserves at the Kin Foundation is released to corporate partners to be used, for example, as incentive payments for decentralized contributions. While it is unclear if Kik and Kin optimally designed the allocation, they apparently thought about issues related to promoting user adoption, incentivizing third-party contributors to the system, controlling inflation, and compensating key personnel and partners while growing the platform.

The case of Kik/Kin leads to the following three observations that apply generally to (blockchain-based) platforms.

(i) Token embedding. It should be clear from the example that tokens are used as a platform currency/local medium of exchange — a “Token Embedding” phenomenon first

[29]Facebook’s role in the creation of Libra coins is similar.

highlighted in CLW. Indeed, in many existing blockchain applications, native tokens are the required or favored medium of exchange.[30] For example, it is cheaper to make international payments and settlements using Ripples (RXP) on the Ripple network; to make profit by providing validation services, OmiseGo (OMG) tokens are required as stakes on the OmiseGo blockchain; even though the Ethereum platform allows other AppCoins and cryptocurrencies, many transactions and fundraising activities are still carried out using Ethers (ETH) because of the convenience and popularity. Moreover, platform owners actively design the rules for token supplies and attributes and use tokens to compensate resource contributors (investors, developers etc.) as well as to manage the platform development.

We note that it is natural and common in practice to introduce platform tokens that agents hold and use because transfers in fiat currencies inevitably rely on centralized third parties such as banks that are subject to the confines of physical locations and jurisdictions. Tokens, in contrast, can be used not only for peer-to-peer exchanges, but also for compensating miners, validators, and other contributors who work to improve the stability and functionality of the ecosystem. This is especially convenient because cryptocurrency miners who maintain network securities under the Proof-of-Work protocol and liquidity providers in a staking-based system are not long-term employees of the platform and demand on spot, reliable payments. Moreover, native coins can be directly linked to the history of transactions and events on the blockchain, a feature other currencies cannot provide.[31]

There are many examples other than the Kin project. Filecoin (FIL) is used as the sole means of payment in the network marketplace to reward miners for block creation in the Filecoin consensus process. Another example is Basic Attention Token (BAT). As Strategic Coin explains in its BAT token launch research report, BAT also functions as a medium exchange between users, advertisers, and publishers who participate in the Brave browser ecosystem. Advertisers purchase ads using BAT tokens, which are then distributed among both publishers and browser users as compensation for hosting the ads and viewing them,

[30] See also Brunnermeier, James, and Landau (2019) who conclude, "Payments are at the center of any economic platform, and all other activities would organize themselves around the central payment functionality." Even though policy makers often generically refer to non-cash-flow-based tokens as "utility tokens," we note that the majority of them are not for redeeming a product or service from the platform owner per se at fixed prices. They simply represent the right to use the platforms to conduct business. These include many of the high-profile projects: Filecoin, Golem, 0x, Civic, Raiden, and Basic Attention Token (BAT). Prices are not pre-set but emerge from markets where the users' token demand meet the platforms' supply.

[31] Kocherlakota (1998) models money as an object that does not enter utility or production functions. He then shows that from a technological point of view, money is equivalent to a primitive form of memory. With the blockchain technology, money is indeed memory. Tokens are useful as means of payment and stores of value precisely because of agents' knowledge of full histories of token-based transactions.

respectively.

The fact that platform ecosystems including blockchain-based ones tend to be mediated by native tokens is only one aspect of token embedding. In principle no one needs to *hold* the native token if its velocity is infinite, i.e., people can instantaneously exchange other currencies with the native tokens. The second aspect of token embedding is that agents actually need to hold the tokens to conduct transactions and perform economic activities. While this is also true for fiat money in practice, blockchain-based systems add at least three more reasons.

First, to incentivize and allocate service flows to decentralized miners or service providers, many tokens are designed such that these agents have to hold the native tokens to earn the right to perform work to maintain the system, be it service provision or recordkeeping. Proof-of-Stake protocols typically fall in this category. These tokens are sometimes referred to as work tokens or staking tokens, and notable implementations include Keep (off-chain private computation), Filecoin (distributed file storage), Truebit (off-chain computation), Livepeer (distributed video encoding), and Gems (decentralized mechanical Turk).[32]

Second, blockchains enable the use of smart contracts—digital contracts allowing terms contingent on decentralized consensus that are typically self-enforcing and tamper-proof through automated execution. Smart contracts need to automate transactions once certain contingencies are fulfilled, which in turn requires a certain amount of tokens to be "escrowed" during the episode that such contingencies may be triggered.

Third, because the generation of decentralized consensus takes time, there exist technical and economic limits on how quickly transactions can be validated and recorded (Chiu and Koeppl, 2017). While many protocols such as the Lightening Network and Ethereum process transactions significantly faster than Bitcoin (seconds versus 10-11 minutes), the decentralized nature of the validation means it takes time to ensure robustness and synchronization of the consensus. During the confirmation period, agents have to hold tokens.

(ii) Dynamic token supply and platform management. Admittedly, much of the discussion on cryptocurrency has focused on its role as a competitor for fiat currency for general payments. In a way, fiat currencies are also an extreme form of platform tokens in

[32]To enforce a mechanism to penalize workers who fail to perform their job to some pre-specified standard, work tokens have to be held as collateral. For example, in Filecoin, service providers contractually commit to storing some data with 24/7 access and some minimum bandwidth guarantee for a specified period of time. During the contract term, service providers must "escrow" some number of Filecoin, which can be automatically slashed (taken away) should they fail to perform the service.

that people "join" the platform by recognizing their value and accepting them (Gans and Halaburda, 2015), and the platform being the broader economy. What distinguishes tokens on digital platforms is that the adoption is no longer dictated by physical constraints: it is way more costly to adopt a different fiat currency by emigrating to a different country, but switching among digital platforms are relatively easy, which implies that the adoption of digital platforms are more endogenous than the adoption of a fiat currency.

Not only is user adoption on platforms endogenous, the development of platforms is as well. Just like executives manage firms' hiring and investment dynamically, tokens allow platform owners to manage the contributions from dispersed agents in the network and thus manage the evolution of the platform. It is not only about a one-time ICO. Blockchain-based platforms often pay workers (contributors) on the spot with their tokens on an on-going basis instead of a contract that promises the typical deferred compensation.[33]

For example, Kin tokens were issued to allow broad adoption and contribution by developers and users to foster a "virtuous cycle in which the ecosystem grows in both size and quality" (Livingston, 2017). Through measures such as capping individual purchases at $4,400, Kik structured the offering to encourage actual usage of the tokens as a medium of exchange instead of hoarding and speculation. It is believed that a token-based ecosystem of independent users and developers would have the right incentives to grow the platform. Indeed, by the end of 2018, Kin exceeded Ether and Bitcoin in blockchain user activities according to blocktivity.info. Both the Apple App and Google Play Stores accept Kin as a digital currency; the Kin ecosystem has also integrated dozens of third-party apps including Perfect 365, a top-rated augmented-reality app for photo makeup with over 100 million users, and Nearby, a popular app with millions of users for meeting new people. The Kin Rewards Engine schema dynamically incentivize dispersed agents in the system to grow the platform, so that founders' effort needs not play a central role after launching the platform.

We should remind the readers that the use of platform tokens is not necessarily decentralized or blockchain-based. Even a traditional, centralized transaction platform may see the opportunity to create open interfaces - APIs (e.g., Uber has opened up APIs to enable third parties to add value) and use platform tokens. Before the Kin project, Kik was using a platform local currency even though it was not blockchain-based; many community-based

[33]Gathering resources through spot payment instead of deferred compensation is a salient feature of blockchain-based platforms. Deferred compensation is common in traditional firms and economic theories. Note that even in the simplest setting of production where firms combine labor and capital into output (often through a Cobb-Douglas function), there exists an implicit assumption that firms obtain inputs and then pay workers and investors after production.

companies such as Facebook, Tencent, Microsoft, and Amazon have also introduced platform tokens before (see Gans and Halaburda, 2015, for an excellent discussion). Other notable examples of non-blockhain tokens include those introduced in online games, such as Linden dollar for the game Second Life and WoW Gold for the game World of Warcraft.

(iii) Entrepreneurs' token payouts and buy-back. How entrepreneurs get compensated through tokens is under-discussed in academic studies yet is important in practice. In the Kik/Kin example, founders, early investors, and key personnel get tokens which they can sell in secondary markets. This is a form of seigniorage.[34] What distinguishes blockchain-based platforms is that the issuance of tokens can be rule-based whereas inflation presents a perennial concern with fiat money run by central banks that are potentially under political influences. Indeed, many token designs specifically guard against inflation, for example, by pre-specifying the level or growth rate of token supply. Bitcoin supply is capped at 21 million and Dfinity, at 469.21 million. Platforms like Kin also employs more sophisticated token-supply policies, balancing the rule-based and discretionary approeaches, in order to optimally incentivize the platform participants and compensate the founders.

Precisely because tokens are used to compensate platform owners, founding entrepreneurs and designers care about how "inflated" the ecosystem is because they care about the platform's franchise value going forward. This leads to many platforms also burning tokens to reduce inflation. Kin burned about 10% of tokens during the migration from Etherem to its own blockchain.[35] Another recent example of discretionary reduction of token in supply is the Synereo team which burned 33% of its cryptocurrency reserves on March 31, 2018 after meeting development goals with fewer tokens (AMP) than initially projected.[36]

Burning tokens out of circulation by buying tokens back from the secondary market requires cash reserves held by foundations or other entities that are in charge of platform operation. To bolster community activity and maintain the stability of token market, TRON Foundation announced a $20 Million token buy-back plan on June 25, 2019 (one of the largest token buy-back plan at the that time).[37] Its cash reserve was partly built by the $70 million raised in an initial coin offering in 2017. Such cash reserves comes from operating profits,

[34]Entrepreneurs earn seigniorage for building infrastructure for and promoting platform networks. Even for stablecoins such as JPM Coin and Libra, the core networks of powerful institutions the founders foster add to attracting users. Key members in Libra are also compensated through Libra Investment Tokens.

[35]https://medium.com/kinblog/blockchain-strategy-update-next-steps-in-migrating-to-the-kin-blockchain-aed99e209654

[36]https://synereo.com/burn-amps/

[37]https://cointelegraph.com/news/tron-foundation-announces-20-million-buyback-plan

(initial) coin offerings or venture capital backing.[38] Spending cash incurs both a direct cost and a shadow price that is ultimately attributed to the standard costs of external financing (e.g., Bolton, Chen, and Wang, 2011; Décamps, Gryglewicz, Morellec, and Villeneuve, 2016). In our model, the parameter χ captures this economic force.

Finally, as in our model, token burning in practice often depends on the stages of platform development. In preparation for a technical upgrade of its tokens, the Swiss-based crypto platform Eidoo announced in June 2020 a burning of 28 million $EDO tokens. Binance, which is a cryptocurrency exchange financed by VCs such as Sequoia, burned 2.5 million BNB tokens in July 2018 (worth approximately $30 million).[39] The company also planned to burn tokens worth 20 percent of its profits each year, and then stopped such operation in January 2020. Next, we discuss the discretion and commitment in token supply.

(iv) Discretion in dynamic token allocation. The platform owners' discretion is a salient feature of our baseline model. Many traditional centralized platforms and blockchain-based platforms allow the designers and owners to dynamically decide token allocations. While public blockchains assign relatively little tokens under the control of platforms, for example, less than 1% of Ether is owned by the Ethereum platform, many other platforms do have discretion in token supply.[40] While many crypto-tokens have pre-specified long-run maximum supply and certain rules against inflation, the numbers are often ad hoc. Moreover, the maximum token supply is large and relevant only in the distant future, not to mention that token burning renders the caps on supply effectively non-binding (except in extreme market conditions). So its impact on short-term platform development and user activities is limited. Some platforms do not even have a maximum supply specified (Ethereum being the most notable example).

Therefore, not all token supply is pre-set. The Kin foundation's Rewards Engine schema discussed earlier is just one example of discretionary dynamic token allocation. An excellent article by Kajpust (2019) documents that in general, token foundations' operations are not very transparent, disclosure practices/requirements are only gradually introduced, and token allocation allows much discretion. For example, as of Jan 2019, Stellar is effectively in

[38]Notable blockchain-focused venture capital firms include include A16z Crypto (a subsidiary of Andreessen Horowitz), Pantera Capital (a U.S.-based investment fund), Coinbase Ventures (VC arm of crypto exchange Coinbase), and Yeoman's Capital (active early-stage angel investor), IDG Capital (angel and seed investments in Ripple, Circle, etc.).

[39]https://binance.zendesk.com/hc/en-us/articles/360007242192-Binance-4th-Quarter-Token-Burn

[40]https://www.cryptocompare.com/media/1383735/pdfs-termsandconditionsoftheethereumgenesissale.pdf.

control of over 85% of Lumen tokens. The future token distribution is fully centralized, and is by no means not written in stone. Moreover, Stellar Operational Fund and Development Foundation (Stellar.org) manage over 10% of Lumens through the Build Challenge that distributes millions of Lumens to is proposed challenge.[41]

As another example, the complaint of Securities and Exchange Commission (SEC) against Telegram Group Inc. and its wholly owned subsidiary TON Issuer Inc. (allegation No. 74) describes the firm's discretion over the release of unsold Grams,[42] The primers issued to investors in 2017 and 2018 explain that "[f]our percent of the supply (200 million Grams) will be reserved for the development team with a 4–18 year vesting period" and at least 52% of the supply will be "retained by the TON Reserve to protect the nascent cryptocurrency from speculative trading." It also explained that the TON Reserve would transfer its Grams to the TON Foundation, and that the "founders of Telegram will be responsible for the efficient use of funds resulting from any [additional] sale[s]."

Related, YouNow, also currently sued by the SEC, has 10% of their tokens (100,000,000 Props Tokens) allocated to wallets controlled by Props Foundation Public Benefit Corporation (PBC) and is "distributed by Props PBC on a discretionary basis in the form of grants or expense reimbursements to developers building either applications on the Props Network or Network infrastructure, strategic content partners, and other entities directly supporting the growth of the Props Network or sold for cash proceeds."[43]

Yet one more example is that 3 million of Polkadot's DOT tokens, which is 30% of the total number eventually in circulation, are allocated to the Web3 Foundation (led by Gavin Wood, co-founder of Ethereum), and are retained or distributed upon the foundation's discretion.[44]

The key takeaway here is that even though the blockchain technology facilitates commitment as highlighted in Section 5, many current practices do not fully implement such commitment, leaving a significant portion of tokens under the discretion of the platform designers and entrepreneurs. Our analysis starts from the baseline model of discretionary token supply to capture such practice and then moves on to analyze the value added from commitment enabled by blockchain technology.

[41]See also https://www.stellar.org/blog/bitcoin-claim-lumens/ and https://www.stellar.org/blog/bitcoin-claim-lumens-2/.

[42]https://www.sec.gov/litigation/complaints/2019/comp-pr2019-212.pdf.

[43]https://www.sec.gov/Archives/edgar/data/1725129/000162827918000249/filename2.htm.

[44]See, e.g., https://polkadot.network/faq.

Blockchain-based commitment: advantages and limitations. Finally, we summarize the three aspects of blockchain technology that are critical in enabling commitment, including data structure, smart contracting, decentralized data storage, and governance. Then we highlight the advantages of blockchain-based commitment over traditional approaches (e.g., collateral) and discuss the limitations of blockchain-based commitment.

First, the blockchain technology entails a linked-list data structure such that each block of records is time-stamped. Along the consensus chain of blocks, no agent can retroactively modify the information, which prevents ex post tempering and manipulation of data and information. The immutability and distributed structure makes blockchains promising infrastructures for commitment schemes.[45] Cao, Cong, and Yang (2018) and Cao, Cong, Han, Hou, and Yang (2020) provide use cases of such data structure in financial reporting and auditing.

Second, building on the aforementioned data structure, many blockchains allow smart contracts, which utilize computer scripts that automatically execute spot transactions or future contractual promises. Smart-contracting enables certain levels of automation and commitment, without relying on a centralized authority for execution (Buterin et al., 2014; Rastegar, Fotuhi-Firuzabad, and Aminifar, 2012; Tinn, 2019; Holden and Malani, 2018; Bakos and Halaburda, 2019). Cong and He (2018) discuss the applications of smart contracting and industrial organization. Chen, Cong, and Xiao (2019) provide a broader survey on the related issues and applications.

Execution and renegotiation of traditional contracts can be costly. Revelation mechanisms and renegotiation designs rarely show up in practice because they are too complex to implement using traditional technologies and legal methods as they often require multiple stages of structured bargaining. In contrast, the future transactions coded in smart contracts are automatically executed thanks to the immutability of blockchain records. Thus, smart contracts, when applicable, induce less costs than traditional contracting and commitment.

Multi-signature smart contracts are particularly effective in mitigating frauds. For example, escrow Bitcoin wallets (e.g., the system employed by blockchain-based retail platform OpenBazaar) are effective in allowing buyers and sellers to commit to transaction execution.

Third, we should note that blockchain commitments do not come from data structure and smart contracts alone. The decentralized storage and governance of data play important

[45] A commitment scheme is a cryptographic primitive that allows one to commit to a chosen value (or chosen statement) while keeping it hidden to others, with the ability to reveal the committed value later. Commitment schemes such as zero-knowledge proofs are designed to be binding.

roles. Due to the distributed nature of blockchain ledger, abandoning historical records, changing governance protocols, forfeiting existing contracts, etc., all require great efforts of coordination, which makes deviations from pre-committed actions difficult.

Whether consensus is generated in a centralized way or not, the distributed storage also provides greater transparency and monitoring. For example, uncertainty and lack of information that afflict traditional contracting apply to smart contracts as well. But public witness on blockchains makes smart contract less prone to uncertainty in execution and verification of state contingency. It has less interpretation ambiguity too.

Finally, note that the conventional commitment mechanisms, often applied to debt contracts, such as seniority provisions, restrictive covenants, and relationship banking, may reduce firms' financial flexibility and suffer from issues such as reduced capital-market competition and systematic financial fragility. While blockchain-based commitment has its advantages, it is not a panacea for commitment. The space for smart contracting is limited. Information feed from oracles and the Internet of Things (IoTs) is still being developed. That said, the blockchain-based commitment does have its unique applications, especially the lack of reliance on a centralized third party for legal or other enforcement.