STO vs ICO: A Theory of Token Issues Under Moral Hazard and Demand Uncertainty

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Abstract

This paper considers a financing problem for an innovative firm that is considering launching a web-based platform. Our model is the first one that analyzes an entrepreneur's choice between security tokens (via a security token offering (STO)) and utility tokens (via initial coin offering (ICO)). The entrepreneur on one hand faces a large degree of demand uncertainty on his product and on the other hand has to deal with incentive problems of professional blockchain participants who contribute to the development and sales of the product. We argue that utility tokens with profit rights are a better option for the firm compared to straight utility tokens or security tokens because they help the firm better deal with both the moral hazard problems (via profit sharing incentives) and demand uncertainty (they help the firm learn the product demand). This finding is consistent with some recent evidence. The paper also generates new predictions that have not been tested sofar.

Keywords: Entrepreneurial Finance; Blockchain; Initial Coin Offering; Security Token Offering; Moral Hazard; Demand Uncertainty; FinTech

JEL Codes: D82, G32, L11, L26, M13

1 Introduction

Innovative companies account for a significant share of the global market for human capital but they are often constrained in their growth potential as they have difficulty accessing capital markets (Hall (2009)). Blockchain-based initial coin offerings (ICOs) and security token offerings (STOs) promised to provide a new source of financing for such firms. The ICO phenomenon dates back to 2013. Since then, the number and funding of projects has been growing exponentially, with over $20 billion raised by December 2018 (Coinschedule, 2018). In a typical ICO, an entrepreneur raises capital by pre-selling utility tokens

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which give their owners the right to use the company's product or service once it is developed. In 2017, the next step was taken. Fintech companies started to use STOs to finance their projects. In security token offerings (STOs),[1] companies sell tokenized traditional financial instruments, like, for example, equity where tokenholders receive rights on a firm's future profits.[2] The number of STOs is quickly growing. In January 2018 5 STOs were conducted (monthly) while in November/December 2018 there were more than 20 per month and it continues to grow.[3]

ICO and STO research is quickly growing. Most papers are focused on ICOs. Theoretical papers on ICOs include, amomg others, Catalini and Gans (2018), Li and Mann (2018), Govindan and Wilson (2009), Bakos and Ha laburda (2018), Cong and Wang (2018), Lee and Parlour (2018), Garratt and van Oordt (2019) and Miglo (2020a). Reserach on STOs and utility tokens with profit-sharing rights is in its early stages and as we are writing this article it includes several emprical papers (eg. Adhami, Giudici and Martinazzi (2017) and Ante and Fiedler (2019)) but no theoretical paper to the best of our knowledge. Respectively no paper is focused on the choice between ICO, STO and etc. eventhough for many entrepreneurs this issue seems to be very important.[4] In this article we shed some light on these unexplored questions namely what are economic ideas behind issuing security tokens or utility tokens with profit rights and how firms select between different types of tokens.

Our model builds on the following observations. First, ICOs and STOs are characterized by an environement with high uncertainty. A lot of campaigns fail or turn out to be low quality or even fraud in some cases.[5] Firm success in these innovative areas depends crucially on the incentives and efforts of not only the firm itself but on many particpants invloved. For example, an interesting case is Filecoin, which is setting up a network to allow peer-to-peer storage space sharing. Their success depends on action and strategies of so-called miners who are expected to be active participants of their platform. Token design issued by the platform may affect the incentives of parties involved. For example, in the case of Filecoin, miners purchase tokens during the pre-sale.[6] Second, tokens serve as a learning tool for entrepreneurs regarding market demand. By observing the demand for tokens during the initial sale of tokens or by observing

[1] In contrast to utility tokens, security tokens are regulated. The legal structures continue to evolve. In the US, for example, the Securities and Exchange Commission (SEC) applies the Howey test to determine whether an asset qualifies as a security. Essentially, investments are considered securities if money is invested, the investment is expected to yield a profit, the money is invested in a common enterprise and any profit comes from the efforts of a promoter or third party (Ante and Fiedler (2019)).

[2] Ante and Fiedler (2019).

[3] https://hackernoon.com/will-2019-be-the-year-of-the-sto-understanding-stos-security-tokens-market-potential-over-icos-4d2502227220

[4] See, for example, https://blog.polymath.network/minthealth-and-polymath-bring-the-first-healthcare-security-token-to-revolutionize-healthcare-a36884f17e4e

https://www.theblockcrypto.com/2019/06/04/a-conversation-with-carlos-domingo-ceo-and-co-founder-securitize/

[5] See, for example, OECD (2019).

[6] https://coincentral.com/filecoin-beginners-guide-largest-ever-ico/

the token market price, the entrepreneur can learn "crowd wisdom" regarding the platform and its products. Finally, tokens have secondary markets (see, for example, the interview with BlockState CEO Paul Claudius[7]) unlike, for example, venture capital investments. This feature of tokens makes it also different from crowdfunding which typically does not have a secondary market for investments made by funders.[8]

In our model an entrepreneur with an innovative idea considers launching a web-based platform for an infinite number of periods. The demand for the product is highly uncertain so the entrepreneur can make production decisions without learning demand or it can issue tokens prior to making production decisions. The success of the platform also crucially depends on the effort provided by the entrepreneurs and blochchain participants (miners) during the development stage. In order to finance the development of the platform, the entrepreneur can issue tokens. Utility tokens give the right to purchase a product or service on the platform while security tokens give a right on firm profit. The "wisdom of the crowd" aspect of a platform kicks in when the firm is facing demand uncertainty. Without utility tokens, production (and repsectively pricing) decisions of the firm are not optimal. Usage of utility tokens helps the firm to learn the demand and improve its decision-making including production (pricing) decisions. However the shortcoming of utility tokens is that they do not provide much incentive for miners to develop the product. On the other hand security tokens to not provide a flexible tool for learning market demand. We then analyze the trade-off between security tokens and utility tokens for the entrepreneur. We show, for example, that the utility tokens will be preferred if the degree of unceratinty regarding market demand is higher (it increases the learning value of utility tokens).

Next we include utility tokens with proft rights into the basic model. We demonstrate that this type of token dominates regular utility tokens (i.e. without profit rights) or security tokens. Learning opportunities in terms of demand for this kind of token still exists which makes it similar to utility tokens without profit rights. Also in contrast to utility tokens without profit rights, they do a better job of incentivizing miners during the development stage.

Our model provides several predictions most of which have not been tested sofar. Interestingly though, one of our main predictions namely that utility tokens with profit rights can dominate utility tokens without this right is consistent with recent empirical evidence. In a subsample of 253 campaigns, Adhami et al (2017) document higher returns when tokens allow contributors to access a specific service including profit rights. Our results also provide several implications for policymakers and practitioners. First, it explains factors that should be taken into account by managers designing optimal token design for their firms. Secondly it can help different platforms hosting ICOs and STOs compare the suitability of the different types of tokens with a variety of business factors,

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[7] http://www.bcointalk.com/investing/Block-state-CEO-Paul-Claudius-in-an-Interview-In-Switzerland-it-is-much-easier-to-STO-than-they-have-been-in-Germany-h1524.html

[8] See, for example, https://tokenomica.com/blog/security-token-offering-as-an-alternative-to-crowdinvesting/

which ultimately can help platforms deal with different issuers and minimize risks (maximize quality).

KuCoin CEO Michael Gan explains that the advantage of why his business is doing relatively well compared to its competitors and why its tokens have an active and growing market is that their tokens have both utility value and profit sharing rights. It helps on one hand to provide all services to customers but also ensures financial incentives even when markets seems to be bearish. "...As the native token of KuCoin, KCS holders now can enjoy trading fee discount and daily KCS bonus on our platform. ....Also, KCS has gradually been accepted by increasing number of industry partners. You can now use KCS to get a loan on ETHLend, transfer KCS to your friends on Adamant Messenger, pay private expenses with KCS through Aave pay. More use cases will be unveiled this quarter." In many articles KCS is named one of the best dividend paying tokens so it has aspects of both utility tokens and security tokens.[9] There are many other examples of cryptobusinesses that use similar ideas including Binance, Medpath, XWIN, Elephant, Props, Treecoin, XOV etc.

Garratt et al (2019) study the effect of entrepreneurial moral hazard on ICO outcomes and find conditions for when an ICO is a better choice than traditional debt or venture capital. Compared to Garratt et al (2019), we also study the incentives of other blockchain participants related to moral hazard problems. In Catalini et al (2018) an ICO allows an entrepreneur to generate buyer competition for the token, which, in turn, reveals consumer value without the entrepreneurs having to know, ex ante, consumer willingness to pay. In our paper, on the other hand, tokens can help entrepreneur learn market demand in each period by observing the token price on the secondary market. Compared to the papers mentioned above, we also study STO and utility tokens with profit rights.

The rest of the paper is organized as follows. Section 2 describes the basic model and some preliminary results. Section 3 provides an anlysis for the model with moral hazard and demand uncertainty. Section 4 analyzes the role of utility tokens with profit sharing rights. Section 5 discusses the consistency of the model's predictions with observed empirical evidence. Section 6 discusses the model's robustness and its potential extensions and Section 7 is a conclusion to the study.

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[9] https://www.cryptosquawk.com/kucoin-shares-review-the-dividend-paying-exchange-token/

https://www.kucoin.com/news/en-michael-ama-tron-community-exchanges-are-naturally-for-staking-services

https://medium.com/altcoin-magazine/interview-with-michael-gan-ceo-of-kucoin-ae0b089e2a0b

https://www.youtube.com/watch?v=pKlPiw943yI&t=34s

2 The Model Description and Some Preliminaries

An innovative firm has monopoly power over its idea of creating a website platform selling a product/service for an infinite number of periods. The platform's quality depends on the effort provided by the entrepreneur (e_1) and the blockchain participants (we call them miners for shortness) (e_2). The cost of effort is $\frac{e_j^2}{2}$, $j = 1, 2$.[10] During the operational stages of the platform, the demand for product in each period is expected to be driven by the following demand function: $q = v - p$, where p is the price, q is the quantity demanded. In each period v can be either high (v_h) or low (v_l). The probability of high demand is μ. Let Π_n be the firm's operational profit in period n and δ is the discount factor. Respectively $E(e_1, e_2) \sum_n \frac{\Pi_n}{(1+\delta)^n}$ is the present value of the firm's earnings where $E(e_1, e_2)$ is a factor that reflects the platform's quality. We assume

$$E(e_1, e_2) = e_1 + e_2 \tag{1}$$

The calculations of Π_n as well as the way the firm's earnings will be distributed depend on the firm's financing strategy. To finance the development of the product the firm can sell tokens. Tokens may vary in design. They can be utility tokens which give the tokenholder the right to purchase the product on the platform. They can also be security tokens which give tokenholders profit sharing rights. The firm is owned by an entrepreneur.

Utility tokens. Initially, i.e. before the platform is launched, the firm sells tokens to miners for the price p_0.[11] The total number of tokens is normalized to unity without loss of generality. As we will see, the relative fractions of tokens owned by the entrepreneur, miners and public are important. After the first issue of tokens is sold, the entrepreneur and the miners provide their efforts. Miners then trade tokens on the secondary market. After that the platform is launched. In each period, the entrepreneur sells tokens received for selling the product in the previous period. After that he determines the level of production. At the end of each period the produced items are exchanged for tokens.

Security tokens. The firm selects the fraction of equity α that will belong to security token holders and sells them during the STO to miners. After that the entrepreneur and miners select their production efforts. The platform is launched for an infinite number of periods. In each period, the firm produces its products/services and sells them to the public. The firm's earnings are distributed pro-rata according to the number of tokens owned by each tokenholder.

First consider the symmetric information scenarios without moral hazard problems for the different types of tokens. We assume that v is given and the quality of platform E is also given and equals 1 for simplicity and it does not depend on any efforts made by the entrepreneur or miners.

[10] In Section 6 we discuss the model's assumptions including the ways of modelling moral hazard, risk-aversion etc..

[11] They can be paid for with fiat money and a cryptocurrencies such as Bitcoin, Euther etc.

2.1 Utility tokens

The timing of events is present in Figure 1.

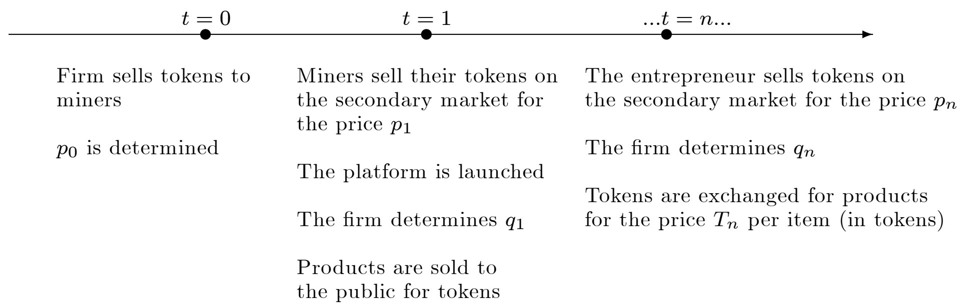

Figure 1. The sequence of events for utility tokens.

We begin the solution by working backwards. Consider the operational stage. In period n, the entrepreneur sells tokens for the price p_n. After tokens are sold, the firm determines q_n. Tokenholders then use their tokens to buy products. Equilibrium is determined by the following conditions: 1) after selling tokens the firm maximizes its profit in tokens (since tokens are the only medium of exchange on the platform), which equals $q_n T_n$ (production-incentive constraint)

2) demand equilibrium:

$$q_n = v - P_n \tag{2}$$

where P_n is the cost of the product for the public:

$$P_n = T_n p_n \tag{3}$$

Taking into account (2) and (3), the entrepreneur's objective function can be written as $\frac{(v-q_n)q_n}{p_n}$. The optimal q_n equals (note that by the time the production decision should be made, tokens are sold and p_n is determined)

$$q_n = \frac{v}{2} \tag{4}$$

and the entrepreneur's profit (in tokens) equals:

$$\frac{v^2}{4p_n}$$

From (2) and (4) we have:

$$P_n = \frac{v}{2}$$

This implies a non-arbitrage condition for consumers (i.e the cost of tokens for consumers (p_n) equals the cost of products offered by the entrepreneur taking into account the demand function):

$$\frac{v}{2} = T_n p_n$$

Token market equilibrium (supply equals demand) is described by the following condition:

$$q_n T_n = 1$$

This implies:

$$T_n = \frac{2}{v}$$

$$p_n = \Pi_n = \frac{v^2}{4}$$

The present value of the firm's profits equals $\Pi = \sum_n \frac{\Pi_n}{(1+\delta)^n}$ and the present value of the entrepreneur's earnings equals

$$\frac{v^2}{4\delta} - \frac{v^2}{4(1+\delta)} = \frac{v^2}{4\delta(1+\delta)} \tag{5}$$

The second term is substracted because the entrepreneur does not sell tokens during period 1 (it is done by the miners; note that without moral hazard the results would not change if the entrepreneur sold it directly to the public).

At the beginning of period 1, miners sell their tokens on the secondary market for the value:

$$p_1 = \frac{v^2}{4}$$

When selling tokens, the entrepreneur's total profit is:

$$p_0 + \frac{v^2}{4\delta(1+\delta)}$$

under the condition that miners' profits covers their investment costs

$$\frac{p_1}{1+\delta} = \frac{v^2}{4(1+\delta)} \geq p_0$$

We assume that there is a large number of miners so they agree to invest an amount equal to the present value of their future profits. The entrepreneur's total profit equals

$$\Pi = \frac{v^2}{4\delta(1+\delta)} + \frac{v^2}{4(1+\delta)} = \frac{v^2}{4\delta} \tag{6}$$

2.2 Security tokens

The timing of events is presented in Figure 2.

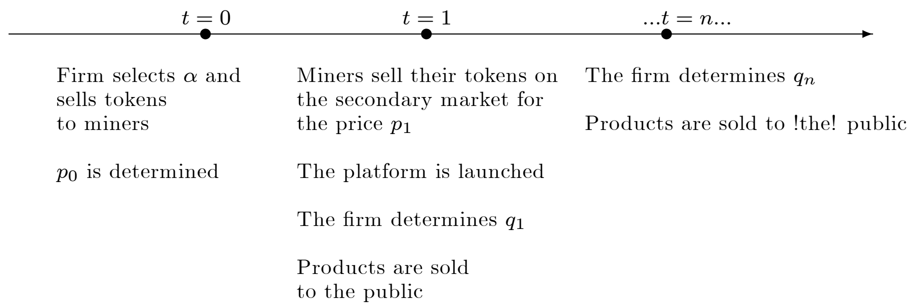

Figure 2. The sequence of events for security tokens.

Consider the operational stage. In period n there are q_n items produced. The firm's objective function can be written as $(v - q_n)q_n$. The optimal q equals

$$q_n = \frac{v}{2}$$

and the entrepreneur's profit equals:

$$\frac{(1-\alpha)v^2}{4}$$

The present value of the entrepreneur's profits equals $\Pi = \sum_n \frac{(1-\alpha)p_n q_n}{(1+\delta)^n}$

$$\frac{(1-\alpha)v^2}{4\delta}$$

The miners' profit equals:

$$\frac{\alpha v^2}{4\delta}$$

When choosing α, the entrepreneur maximizes:

$$p_0 + \frac{(1-\alpha)v^2}{4\delta}$$

under the condition that the miners' profit covers their investment cost

$$p_0 = \frac{\alpha v^2}{4\delta}$$

The entrepreneur's total profit equals then

$$\Pi = \frac{\alpha v^2}{4\delta} + \frac{(1-\alpha)v^2}{4\delta} = \frac{v^2}{4\delta} \tag{7}$$

Lemma 1. *Without moral hazard and demand uncertainty, the firm is indifferent between the different types of tokens.*

Proof. Follows from the comparison of (6) and (7).

This result is not surprising given that in the absence of any financial market imperfections every type of financing should have the same result (similar to Modigliani-Miller proposition (1958)).

3 Product Development, Market Uncertainty and Incentives

In this section we analyze the role of moral hazard and market uncertainty on the firm's choice of tokens. The entrepreneur and miners provide efforts in the development stage of the platform that affect its quality. The token design affects the incentives of all the parties involved. Also the market demand for platform products is uncertain. The token design affects the platform ability to learn information about market demand before the entrepreneur makes his production decisions.

The timing of events for utility tokens is present in Figure 3.

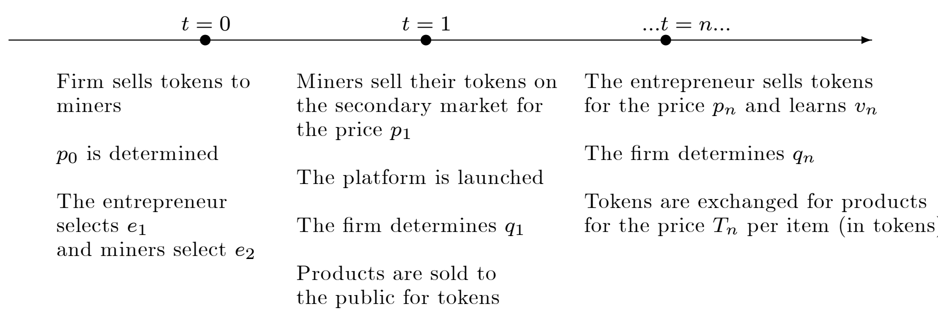

Figure 3. The sequence of events with moral hazard and market uncertainty for utility tokens.

The timing of events for security tokens is present in Figure 4.

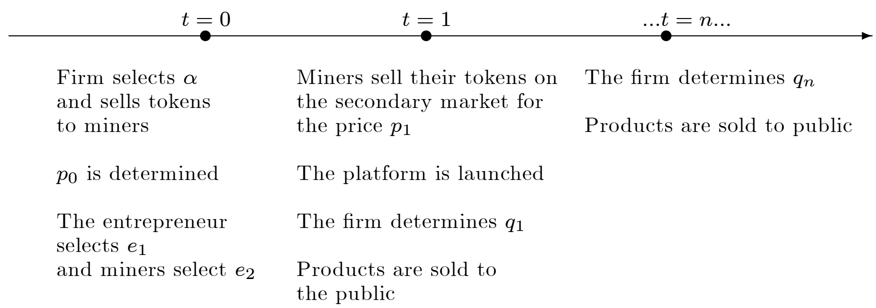

Figure 4. The sequence of events with moral hazard and market uncertainty for security tokens.

We will proceed in 3 steps. First we will consider the case with moral hazard without market unceratinty. Next we will consider the implications of market uncertainty and finally we will consider them together.

3.1 Moral hazard

We start with utility tokens.

3.1.1 Utility tokens

We begin the solution by working backwards. Consider the operational stage. Similarly to the previous section, we get that the present value of the entrepreneur's profits equals

$$E(e_1, e_2)(\frac{v^2}{4\delta} - \frac{v^2}{4(1+\delta)})$$

The difference with the previous case is that the quality of the platform was given but here it depends on efforts provided by the entrepreneur and miners. At the beginning of period 1, miners sell their tokens on the secondary market for the value:

$$p_1 = E(e_1, e_2)\frac{v^2}{4}$$

At $n = 0$, the entrepreneur chooses e_1 to maximize

$$E(e_1, e_2)(\frac{v^2}{4\delta} - \frac{v^2}{4(1+\delta)}) - \frac{e_1^2}{2}$$

Taking into account (1), this equals

$$\frac{(e_1 + e_2)v^2}{4\delta} - \frac{(e_1 + e_2)v^2}{4(1+\delta)} - \frac{e_1^2}{2} \tag{8}$$

Optimal e_1 equals:

$$e_1 = \frac{v^2}{4\delta(1+\delta)} \tag{9}$$

Miners chose e_2 to maximize their discounted earnings from selling tokens at $t = 1$ minus the cost of effort:

$$\frac{p_1}{1+\delta} - \frac{e_2^2}{2} = E(e_1, e_2)\frac{v^2}{4(1+\delta)} - \frac{e_2^2}{2}$$

Taking into account (1), this equals

$$\frac{(e_1+e_2)v^2}{4(1+\delta)} - \frac{e_2^2}{2} \tag{10}$$

Optimal e_2 equals:

$$e_2 = \frac{v^2}{4(1+\delta)} \tag{11}$$

(9) and (11) imply

$$e_1 + e_2 = \frac{v^2}{4\delta} \tag{12}$$

It implies that (8) equals:

$$\frac{v^4}{16\delta^2} - \frac{v^4}{16(1+\delta)\delta} - \frac{v^4}{32\delta^2(1+\delta)^2} = \frac{(1+2\delta)v^4}{32\delta^2(1+\delta)^2}$$

And (10) equals

$$\frac{v^4}{16\delta(1+\delta)} - \frac{v^4}{32(1+\delta)^2} = \frac{(2+\delta)v^4}{32\delta(1+\delta)^2}$$

When selling tokens, the entrepreneur's total profit is:

$$p_0 + \frac{(1+2\delta)v^4}{32\delta^2(1+\delta)^2}$$

under the condition that miners' net profit covers the investment cost

$$p_0 = \frac{(2+\delta)v^4}{32\delta(1+\delta)^2} \tag{13}$$

The entrepreneur's total profit equals then

$$\Pi = \frac{(2+\delta)v^4}{32\delta(1+\delta)^2} + \frac{(1+2\delta)v^4}{32\delta^2(1+\delta)^2} = \frac{(1+4\delta+\delta^2)v^4}{32\delta^2(1+\delta)^2} \tag{14}$$

3.1.2 Security tokens

Similar to Section 2, the present value of the entrepreneur's profits from operations equals

$$\frac{E(e_1, e_2)(1-\alpha)v^2}{4\delta}$$

The entrepreneur chooses e_1 to maximize

$$\frac{E(e_1, e_2)(1-\alpha)v^2}{4\delta} - \frac{e_1^2}{2}$$

Taking into account (1), this equals

$$\frac{(1-\alpha)(e_1+e_2)v^2}{4\delta} - \frac{e_1^2}{2} \tag{15}$$

Optimal e_1 equals:

$$e_1 = \frac{(1-\alpha)v^2}{4\delta} \tag{16}$$

The miners chose e_2 to maximize:

$$\frac{\alpha v^2}{4\delta} - \frac{e_2^2}{2} = \frac{\alpha(e_1+e_2)v^2}{4\delta} - \frac{e_2^2}{2} \tag{17}$$

The optimal e_2 equals:

$$e_2 = \frac{\alpha v^2}{4\delta} \tag{18}$$

(16) and (18) imply

$$e_1 + e_2 = \frac{v^2}{4\delta}$$

It implies that (15) equals:

$$\frac{(1-\alpha)(e_1+e_2)v^2}{4\delta} - \frac{e_1^2}{2} = \frac{(1-\alpha)(1+\alpha)v^4}{32\delta^2}$$

And (17) equals

$$\frac{\alpha(e_1+e_2)v^2}{4\delta} - \frac{e_2^2}{2} = \frac{(2-\alpha)\alpha v^4}{32\delta^2}$$

When choosing α, the entrepreneur maximizes:

$$\Pi = p_0 + \frac{(1-\alpha)(1+\alpha)v^4}{32\delta^2}$$

subject to

$$p_0 = \frac{(2-\alpha)\alpha v^4}{32\delta^2}$$

It implies

$$\Pi = \frac{(2-\alpha)\alpha v^4}{32\delta^2} + \frac{(1-\alpha)(1+\alpha)v^4}{32\delta^2} = \frac{(1+2\alpha-2\alpha^2)v^4}{32\delta^2}$$

Optimal

$$\alpha = \frac{1}{2}$$

and entrepreneur's profit equals

$$\Pi = \frac{3v^4}{64\delta^2} \tag{19}$$

Lemma 2. *Under moral hazard, the entrepreneur's profit when the firm issues security tokens is higher than with utility tokens.*

Proof. Follows from the comparison of (14) and (19). Indeed the difference between them can be written as $\frac{3v^4}{64\delta^2} - \frac{(1+4\delta+\delta^2)v^4}{32\delta^2(1+\delta)^2} = \frac{(1-\delta)^2 v^4}{64\delta^2(1+\delta)^2} > 0$.

The idea behind Lemma 2 is that miners are better incentivized with security tokens. Miners receive part of the firm's profit for a long period of time and if this part is sufficiently high they provide a higher level of effort than with utility tokens. The entrepreneur's effort is reduced but not by much since the entrepreneur keeps a large fraction of equity in any case for a long period of time in the company. Most importantly when maximizing his objective function initially, the entrepreneur has flexibility in terms of selecting the optimal fraction of equity for selling to miners by taking into account the cost of the miners' effort and his own cost. As one can see from (16) and (18), the entrepreneur and the miner's profits depend on the fraction of profits offered to security token holders. With a proper selection of the fraction of profit offered to security token hoders, the firm can provide a good combination of incentives in the case of security token issues. Under utiltiy tokens the entrepreneur does not have much flexibility in managing the levels of efforts since utility tokens do not give their holders a long-term fraction of the firm's equity so the level of incentives that can be induced with utility tokens is smaller than it is with security tokens.

3.2 Demand uncertainty

Here we assume that in each period the demand for the product offered by the platform is either v_h with probability μ or v_l. Issuing utility tokens helps the entrepreneur learn the demand and helps with production decisions.

3.2.1 Utility tokens

Consider the operational stage. In the beginning of each stage product demand is unknown to the entrepreneur (v_n equals v_h with probability μ and v_l with probability $1-\mu$). In period n, the entrepreneur sells tokens for the price p_n. After tokens are sold, the firm determines q_n. Tokenholders then use their tokens to buy products for the price T_n (in tokens). Equilibrium is determined by the following conditions: 1) after selling tokens the firm maximizes its profit in tokens, which equals $q_n T_n$;

2) demand:

$$q_n = v_j - P_n, j = l, h \tag{20}$$

where P_n is the cost of the product to the public

$$P_n = T_n p_n \tag{21}$$

Taking into account (20) and (21), the entrepreneur's objective function can be written as $\frac{(v_j - q_n)q_n}{p_n}$. The optimal q_n equals

$$q_n = \frac{v_j}{2}$$

and the entrepreneur's profit (in tokens) equals:

$$\frac{v_j^2}{4p_n}$$

Also note that we have:

$$P_n = \frac{v_j}{2}$$

This implies a non-arbitrage condition for consumers:

$$\frac{v_j}{2} = T_n p_n$$

Token market equilibrium:

$$q_n T_n = 1$$

This implies:

$$T_n = \frac{2}{v_j}$$

$$p_n = \Pi_n = \frac{v_j^2}{4}$$

The present value of the firm's profits equals

$$\frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta} - \frac{\mu v_h^2 + (1-\mu)v_l^2}{4(1+\delta)} = \frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta(1+\delta)}$$

The latter term is subtracted because the entrepreneur does not sell tokens during period 1.

In period 1, miners sell their tokens on the secondary market for the value:

$$p_1 = \frac{\mu v_h^2 + (1-\mu)v_l^2}{4}$$

When selling tokens, the entrepreneur's total profit is:

$$\Pi = p_0 + \frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta(1+\delta)}$$

subject to

$$p_0 = \frac{p_1}{1+\delta} = \frac{\mu v_h^2 + (1-\mu)v_l^2}{4(1+\delta)}$$

It implies

$$\Pi = \frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta(1+\delta)} + \frac{\mu v_h^2 + (1-\mu)v_l^2}{4(1+\delta)} = \frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta} \tag{22}$$

3.2.2 Security tokens

Consider the operational stage. In period n the firm produces q_n items. The price of the item depends on the market demand. If it is v_h the price equals $p_n = v_h - q_n$ and if it is v_l the price equals $p_n = v_l - q_n$. When making its production decision, the firm maximizes its expected profit. The firm's objective function can be written as $(\mu v_h + (1-\mu)v_l - q_n)q_n$. Optimal q equals

$$q_n = \frac{\mu v_h + (1-\mu)v_l}{2}$$

and the entrepreneur's profit equals:

$$\frac{(1-\alpha)(\mu v_h + (1-\mu)v_l)^2}{4}$$

The present value of the entrepreneur's profits equals

$$\frac{(1-\alpha)(\mu v_h + (1-\mu)v_l)^2}{4\delta}$$

The miners' profit equals:

$$\frac{\alpha(\mu v_h + (1-\mu)v_l)^2}{4\delta}$$

When choosing α, the entrepreneur maximizes:

$$\Pi = p_0 + \frac{(1-\alpha)(\mu v_h + (1-\mu)v_l)^2}{4\delta}$$

subject to

$$p_0 = \frac{\alpha(\mu v_h + (1-\mu)v_l)^2}{4\delta}$$

It implies

$$\Pi = \frac{\alpha(\mu v_h + (1-\mu)v_l)^2}{4\delta} + \frac{(1-\alpha)(\mu v_h + (1-\mu)v_l)^2}{4\delta} = \frac{(\mu v_h + (1-\mu)v_l)^2}{4\delta} \tag{23}$$

Lemma 3. *Under demand uncertainty, the entrepreneur's profit when the firm issues utility tokens is higher than it is when the firm issues security tokens.*

Proof. Follows from the comparison of (22) and (23). Indeed the difference between them can be written as $\frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta} - \frac{(\mu v_h + (1-\mu)v_l)^2}{4\delta} = \frac{\mu(1-\mu)(v_h - v_l)^2}{4\delta} > 0$.

The idea behind Lemma 3 is that the firm learns the market demand when selling utility tokens, which were collected in the previous period, on the secondary market at the beginning of each period. This is consitent with the idea of learning via "crowd wisdom".

3.3 Moral Hazard and Demand Uncertainty

In this section we analyze token design when market uncertainty and moral hazard are both present.

Proposition 1. *Under moral hazard and demand uncertainty, the firm's profit if it issues utility tokens equals*

$$\frac{(1+4\delta+\delta^2)(\mu v_h^2+(1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2} \tag{24}$$

If the firm issues security tokens, its profit equals

$$\Pi = \frac{3(\mu v_h+(1-\mu)v_l)^4}{64\delta^2} \tag{25}$$

Proof. See Appendix 1.

Naturally, profit in either case increases with the expected demand (v_h, v_l and μ) and and decreases with the discount factor δ.

Proposition 2. *The likelihood of selecting utility tokens increases (respectively the likelihood of selecting security tokens decreases) when μ increases from 0 to $\frac{v_l}{v_l+v_h}$ and decreases when μ increases from $\frac{v_l}{v_l+v_h}$ to 1; when δ increases; for a given value of v_l is positively correlated with the difference between v_h and v_l.*

Proof. We need to compare (24) and (25). The former is greater when

$$\frac{3(\mu v_h+(1-\mu)v_l)^4}{64\delta^2} > \frac{(1+4\delta+\delta^2)(\mu v_h^2+(1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2}$$

or

$$\frac{3(1+\delta)^2}{1+4\delta+\delta^2} > \frac{2(\mu v_h^2+(1-\mu)v_l^2)^2}{(\mu v_h+(1-\mu)v_l)^4} \tag{26}$$

The derivative of right-hand side (RHS; respectivelly LHS will be used for left-hand side) of (26) in μ equals:

$$\frac{(v_h-v_l)(\mu v_h+(1-\mu)v_l)(\frac{v_l}{v_l+v_h}-\mu)}{(\mu v_h^2+(1-\mu)v_l^2)^2} \tag{27}$$

which proves the first part of the proposition. Indeed, the sign of (27) is determined by the sign of $\frac{v_l}{v_l+v_h}-\mu$. It is positive when $\mu < \frac{v_l}{v_l+v_h}$ and is negative otherwise. The derivative of LHS of (26) in δ equals $\frac{6(1+\delta)^2}{(1+4\delta+\delta^2)^2}$, which proves the second part. Finally note that the difference between RHS and LHS of (26) can be written as

$$\frac{3\mu(1-\mu)(v_h-v_l)^2+(3-(1+2\delta-2\delta^2))(v_l+\mu(v_h-v_l))^4}{(1+4\delta+\delta^2)(\mu v_h+(1-\mu)v_l)^4}$$

For a given value of v_l, the derivative of this with respect to v_h-v_l is positive, which proves the last part.

Proposition 2 has an interesting interpretation. Points 1 and 3 are related to the degree of market uncertainty and the amount of information that the entrepreneur can recieve when learning the market demand with tokens. Indeed if $\mu = 0$ or 1 the amount of information is zero since the demand is deterministic. The same holds if μ is either very small or very large because there is a large chance that the demand is either very high or low. However when μ is in the middle the degree of uncertainty is highest since the demand can go either way. The last point is also related to information since a larger the difference between v_h and v_l implies a higher risk from misvaluing the demand. Point 2 implies that securtiy tokens are more sensitive to the value of the discount factor. If it is high then the effect of security tokens as an incentive device is diminished.

The next section show that if the firm is able to issue tokens with profit rights it can improve its overall outcome.

4 Utility Tokens With Profit Rights

Suppose that the firm can issue utility tokens with profit rights. In this case the firm selects the fraction of equity α that belong to tokenholders and sells tokens to miners. After that, the entrepreneur and miners provide their efforts. Miners sell their tokens on the secondary market. The platform is launched for infinite number of periods. At the beginning of each period n, the firm sells tokens to the public. Then the firm determines the level of production q_n and pays dividend d_n to tokenholders. Produced items are then exchanged for tokens.

The timing of events for utility tokens is present in Figure 5.

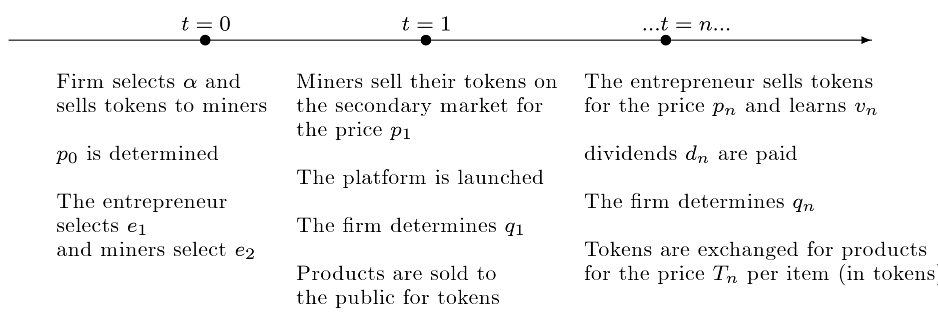

Figure 5. The sequence of events with moral hazard and market uncertainty for utility tokens with profit rights.

Lemma 4. *Without moral hazard and when the demand is known, the entreprneur's profit equals* $\frac{v^2}{4\delta}$.

Proof. See Appendix 2.

This result is not surprising since without market imperfections, the firm's profit is the same as it is with utility tokens or security tokens (see Lemma 1).

Proposition 3. *Under moral hazard and demand uncertainty, the entrepreneur's profit equals:*

$$\frac{3(\mu v_h^2 + (1-\mu)v_l^2)^2}{64\delta^2} \tag{28}$$

Proof. See Appendix 3.

The amount of earnings is positively correlated with v_h, v_l and μ and negatively correlated with δ.

Proposition 4. *The entrepreneur's earnings in case the firm issues utility tokens with profit rights are higher than they are under security tokens or utility tokens without profit rights.*

Proof. We need to compare (24), (25) and (28). First note that (28) is greater than (25). Indeed the difference between them can be written as

$$\frac{3(\mu v_h^2 + (1-\mu)v_l^2)^2}{64\delta^2} - \frac{3(\mu v_h + (1-\mu)v_l)^4}{64\delta^2} = \frac{3\mu^2(1-\mu)^2(v_h - v_l)^4}{64\delta^2} > 0$$

Now compare (28) and (24). The difference between them can be written as

$$\frac{3(\mu v_h^2 + (1-\mu)v_l^2)^2}{64\delta^2} - \frac{(1+4\delta+\delta^2)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2} = \frac{(1-\delta)^2(\mu v_h^2 + (1-\mu)v_l^2)^2}{64\delta^2(1+\delta)^2}$$

which is positive.

5 Implications

Our paper has several implications for an entrepreneurial firm's choice of token design.

Proposition 2 implies that ICO is preferred to STO if the market uncertainty increases or the discount rate decreases. Although this prediction has not been tested directly it is consistent with the spirit of Amsden and Schweizer (2018). They show in their sample of 1,009 projects between 2015 and 2017 that ICO success depends negatively on venture uncertainty and positively on venture quality.

Proposition 3 implies that utility tokens with profit rights dominate security tokens and utility tokens without profit rights. The first part is consistent with Adhami et al (2017). In a subsample of 253 campaigns, Adhami et al (2017) document higher returns when tokens allow contributors to access a specific service including profit rights. The second part has not been tested sofar.

Our model is also consistent with the existence of a positive correlation between the platform's quality and the amount raised during an ICO (see, for example, Ante, Sandner and Fiedler (2018)). Indeed, it follows from (12) and (13) that the amount raised during the ICO equals:

$$p_0 = \frac{(2+\delta)\delta E^2}{2(1+\delta)^2}$$

which means that p_0 is positively correlated with E.

6 The Model Extensions And Robustness

Other types of moral hazard. In our model, the moral hazard takes place because, for example, the particpants' equity stake in the firm is reduced while his individual effort is costly and this cost is not shared. This approach is very common in financing literature (starting with Jensen and Meckling (1976)) and typically creates an agency cost of equity financing. There are many different ways to analyze moral hazard issues, for example, to explicitely assume that the entreprneurs can "steal" money from the firm. In this case the entrepreneur trades-off private benefits from "inefficient" investments and the cost incurred in the case of the firm's bankruptcy. The entrepreneur's objective function can be made more complicated by including, for example, some bonuses from "good" investments. One can also consider an alternative function for a joint result of efforts provided by entrepreneurs and miners. At this point, however, we do not see which parts of our ideas can be affected qualitatively without singificantly complicating the model's solutions so we leave it for future research.

Mixed financing and more types of financing. Unlike capital structure literature, where a debt/equity mix is a very common strategy (as opposed to pure equity or pure debt financing),[12] simultaneously issuing different types of tokens has not shown to be common. Nevertheless, if mixed financing is allowed in period 1, most results will stand. In fact, qualitatively if the firm decidies to issue two types of tokens (utility tokens and security tokens) the results are very similar to issuing utility tokens with profit sharing rights. Note that this strategy seems to be quite popular in practice. For example the CEO of Minthealth Samir Damiani stated the following in one of his interviews: "You will absolutely see the rise of the security token. In fact, industry analysts and leaders predict that 25% ($20 Trillion) of the existing global equity market of $80 Trillion will be security tokens in the next 3 to 5 years, driven primarily by the massive influx of institutional capital. The security token is an incredible tool for companies as they enable stakeholders to participate in the growth of a company and reap the benefits of its success in an SEC compliant manner.....As for the novel dual token structure, we see this as necessary for our company, and likely will become more common in the future. Several industries can benefit from incentivizing consumers. A growing spectrum of industries already have loyalty programs (think Amazon, CVS, Amex etc). As more companies leverage Blockchain, it is likely the fruits of a dual token structure will become more apparent and widely leveraged."[13] These ideas are very similar to the ones

[12] For a review of capital structure literature see, among others, Harris and Raviv (1991) or Miglo (2011). For a traditional analysis of the capital structure of internet companies see, for example, Miglo, Lee and Liang (2014).

[13] https://blog.polymath.network/minthealth-and-polymath-bring-the-first-healthcare-security-token-to-revolutionize-healthcare-a36884f17e4e

https://hackernoon.com/how-to-do-an-sto-an-exclusive-interview-with-the-founder-of-minthealth-ba24be0c6025 suggested in this paper. In fact, Minthealth has decided to issue two types of tokens. and its motivations are quite similar to the ideas in this article. Dual token structure is definitely an interesting direction for future research.

Two stages. One can assume that the firm issues tokens in two stages. For example in case of utiltiy tokens the firm sells a fraction t of tokens to miners and then $1-t$ to the public. As far as we can see, the results will not change with the introduction of this assumption however if one introduces for example two development periods in the model with two different efforts in each period (a dynamic extension of the model) the results will change at least quantitatively. It is hard to predict the consequnes of such a chnage so it is difficult to judge if it is a promising avenue for future research.

Voting rights. One can futher extend the model by allowing the firm to develop more than one project in the initial stage with different utilities for the entrepreneur, the miners and the public and let tokenhoders particpate in the decision-making process etc.

Asymmetric information. In our paper we focus on ex-post asymmetric information, i.e an environment where platform quality depends on the effort of its deloppers. One can consider a model with ex-ante asymmetric information where the entrepreneur initially has some signals about its platform and would like to signal it to the market via tokens issue. It is an intersting avenue for future analysis but it is beyond the scope of our model.[14]

7 Conclusions

This article is the first one that offers a model of the choice between ICO and STO for an innovative firm looking to fund the development of its platform. Existing literature usually focuses on ICOs. Our paper is also the first one that has a theoretical model of STO as well as an analysis of utility tokens with profit sharing rights. The topic is a highly growing area among researchers and practioners. Our model is based on two important features of innovative firms dealing with the development of FinTech related products. First, moral hazard problems related to the developmet of platforms. The reason for this is that the quality of a platform is is highly uncertain to participants and the token design can affect the incentives of the parties invloved. Secondly, tokens have secondary markets unlike venture capital investments or crowdfunding. We study how the design of tokens can help the firm learn information about the demand by observing token price on the secondary market. We find that utility tokens are prefered to secutiy tokens when the degree of uncertainty is high. We also find that security tokens may be prefered if the moral hazard problem is important. We then analyze the role of utility tokens with profit sharing rights and find that these tokens are more profitable for the entrepreneur compared to utility tokens without profit rights and security tokens. Most of our model's

[14] See, for example, Belleflamme et al (2014), Miglo et al (2019) and Miglo (2020b) for the analysis of the role of asymmetric information in crowdfunding.

predictions are new and have not yet been tested but they seem to be consistent to some extent with recent empirical evidence, eg. Adhami et al (2017).

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Appendix

Appendix 1. Proof of Proposition 1. Utility tokens. Similarly to sections 3.1 and 3.2, we get that the present value of the entrepreneur's profits equals

$$\frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta} - \frac{\mu v_h^2 + (1-\mu)v_l^2}{4(1+\delta)}$$

In period 1, the expected value of tokens sold by miners equals:

$$p_1 = \frac{\mu v_h^2 + (1-\mu)v_l^2}{4}$$

In period 0, the entrepreneur choses e_1 to maximize

$$\frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta} - \frac{\mu v_h^2 + (1-\mu)v_l^2}{4(1+\delta)} - \frac{e_1^2}{2}$$

Taking into account (1), this equals

$$\frac{(e_1+e_2)(\mu v_h^2 + (1-\mu)v_l^2)}{4\delta} - \frac{(e_1+e_2)(\mu v_h^2 + (1-\mu)v_l^2)}{4(1+\delta)} - \frac{e_1^2}{2} \tag{29}$$

The optimal e_1 equals:

$$e_1 = \frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta(1+\delta)} \tag{30}$$

The miners chose e_2 to maximize:

$$\frac{p_2}{1+\delta} - \frac{e_2^2}{2} = \frac{\mu v_h^2 + (1-\mu)v_l^2}{4(1+\delta)} - \frac{e_2^2}{2}$$

Taking into account (1), this equals

$$\frac{(e_1+e_2)(\mu v_h^2 + (1-\mu)v_l^2)}{4(1+\delta)} - \frac{e_2^2}{2} \tag{31}$$

The optimal e_2 equals:

$$e_2 = \frac{\mu v_h^2 + (1-\mu)v_l^2}{4(1+\delta)} \tag{32}$$

(30) and (32) imply

$$e_1 + e_2 = \frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta}$$

This implies that (29) equals:

$$\frac{(\mu v_h^2 + (1-\mu)v_l^2)^2}{16\delta^2} - \frac{(\mu v_h^2 + (1-\mu)v_l^2)^2}{16\delta(1+\delta)} - \frac{(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2} = \frac{(1+2\delta)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2}$$

And (31) equals

$$\frac{(\mu v_h^2 + (1-\mu)v_l^2)^2}{16\delta(1+\delta)} - \frac{(\mu v_h^2 + (1-\mu)v_l^2)^2}{32(1+\delta)^2} = \frac{(2+\delta)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta(1+\delta)^2}$$

When selling tokens, the entrepreneur's total profit is:

$$\Pi = p_0 + \frac{(1+2\delta)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2}$$

subject to

$$p_0 = \frac{(2+\delta)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta(1+\delta)^2}$$

It implies

$$\Pi = \frac{(2+\delta)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta(1+\delta)^2} + \frac{(1+2\delta)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2} =$$

$$= \frac{(1+4\delta+\delta^2)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2} \tag{33}$$

Security tokens. Similarly to sections 3.1 and 3.2, we get that the present value of the entrepreneur's profits equals

$$\frac{(1-\alpha)(\mu v_h + (1-\mu)v_l)^2}{4\delta}$$

In period 1, the firm choses e_1 to maximize

$$\frac{(1-\alpha)(\mu v_h + (1-\mu)v_l)^2}{4\delta} - \frac{e_1^2}{2}$$

Taking into account (**??**), this equals

$$\frac{(1-\alpha)(e_1+e_2)(\mu v_h + (1-\mu)v_l)^2}{4\delta} - \frac{e_1^2}{2} \tag{34}$$

Optimal e_1 equals:

$$e_1 = \frac{(1-\alpha)(\mu v_h + (1-\mu)v_l)^2}{4\delta} \tag{35}$$

Miners chose e_2 to maximize:

$$\frac{\alpha(\mu v_h + (1-\mu)v_l)^2}{4\delta} - \frac{e_2^2}{2} = \frac{\alpha(e_1+e_2)(\mu v_h + (1-\mu)v_l)^2}{4\delta} - \frac{e_2^2}{2}$$

Optimal e_2 equals:

$$e_2 = \frac{\alpha(\mu v_h + (1-\mu)v_l)^2}{4\delta} \tag{36}$$

(35) and (36) imply

$$e_1 + e_2 = \frac{(\mu v_h + (1-\mu)v_l)^2}{4\delta}$$

It imply that (34) equals:

$$\frac{(1-\alpha)(e_1+e_2)v^2}{4\delta} - \frac{e_1^2}{2} = \frac{(1-\alpha)(1+\alpha)(\mu v_h + (1-\mu)v_l)^4}{32\delta^2}$$

And (**??**) equals

$$\frac{\alpha(e_1+e_2)(\mu v_h + (1-\mu)v_l)^2}{4\delta} - \frac{e_2^2}{2} = \frac{(2-\alpha)\alpha(\mu v_h + (1-\mu)v_l)^4}{32\delta^2}$$

When choosing α, the entrepreneur maximizes:

$$\Pi = p_0 + \frac{(1-\alpha)(1+\alpha)(\mu v_h + (1-\mu)v_l)^4}{32\delta^2}$$

subject to

$$p_0 = \frac{(2-\alpha)\alpha(\mu v_h + (1-\mu)v_l)^4}{32\delta^2}$$

It implies

$$\Pi = \frac{(2-\alpha)\alpha(\mu v_h + (1-\mu)v_l)^4}{32\delta^2} + \frac{(1-\alpha)(1+\alpha)(\mu v_h + (1-\mu)v_l)^4}{32\delta^2} =$$

$$= \frac{(1+2\alpha-2\alpha^2)(\mu v_h + (1-\mu)v_l)^4}{32\delta^2}$$

Optimal

$$\alpha = \frac{1}{2}$$

and entrepreneur's profit equals

$$\Pi = \frac{3(\mu v_h + (1-\mu)v_l)^4}{64\delta^2} \tag{37}$$

Appendix 2. Proof of Lemma 4. We begin the solution by backwards. Consider operational stage. In period n there are q_n items produced. Tokenholders use their tokens to buy products. Equilibrium is determined by the following conditions: 1) The entrepreneur maximizes his profit in tokens, which equals $q_n T_n$; 2) demand:

$$q_n = v - P_n \tag{38}$$

where the cost of service for the public (P_n):

$$P_n = T_n p_n - \frac{d_n}{q_n} \tag{39}$$

Here d_n is the dividend paid by the firm. We assume that each period the firm distributes its profit pro-rata according to number of tokens per holder. Taking into account (38) and (39), we have that the entrepreneur's objective function can be written as $\frac{(v-q_n)q_n}{p_n}$. Optimal q equals

$$q_n = \frac{v}{2}$$

and the entrepreneur's profit equals:

$$\frac{v^2}{4}$$

Also note that we have:

$$P_n = \frac{v}{2}$$

$$T_n = \frac{2}{v}$$

$$d_n = \alpha\frac{v^2}{4}$$

$$p_n = \frac{P_n + d_n/q_n}{T_n} = \frac{v(v+\alpha v)}{4}$$

The present value of the entrepreneur's profits equals

$$\frac{v^2}{4\delta} - \frac{v(v+\alpha v)}{4(1+\delta)}$$

In period 2, miners sell their tokens on the secondary market for the value:

$$p_1 = \frac{v(v+\alpha v)}{4}$$

When choosing α, the entrepreneur maximizes:

$$\Pi = p_0 + \frac{v^2}{4\delta} - \frac{v(v+\alpha v)}{4(1+\delta)}$$

subject to

$$p_0 = \frac{v(v+\alpha v)}{4(1+\delta)}$$

It implies

$$\Pi = \frac{v(v+\alpha v)}{4(1+\delta)} + \frac{v^2}{4\delta} - \frac{v(v+\alpha v)}{4(1+\delta)} = \frac{v^2}{4\delta} \tag{40}$$

Appendix 3. Proof of Proposition 3. In period n there are q_n items produced. Tokenholders use their tokens to buy products. Equilibrium is determined by the following conditions: 1) the entrepreneur maximizes his profit in tokens, which equals $q_n T_n$;

2) demand:

$$q_n = v_j - P_n \tag{41}$$

where the cost of the product to the public (P_n):

$$P_n = T_n p_n - \frac{d_n}{q_n} \tag{42}$$

Taking into account (41) and (42), we have that the entrepreneur's objective function can be written as $\frac{(v_j - q_n)q_n}{p_n}$. Optimal q equals

$$q_n = \frac{v_j}{2}$$

and the entrepreneur's profit equals:

$$\frac{v_j^2}{4}$$

Also note that we have:

$$P_n = \frac{v_j}{2}$$

$$T_n = \frac{2}{v_j}$$

$$p_n = \frac{v_j(v_j + \alpha v_j)}{4}$$

The present value of the entrepreneur's profits equals

$$\frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta} - \frac{(\mu v_h^2 + (1-\mu)v_l^2)(1+\alpha)}{4(1+\delta)}$$

In period 1, miners sell their tokens on the secondary market for the value:

$$p_1 = \frac{(\mu v_h^2 + (1-\mu)v_l^2)(1+\alpha)}{4}$$

In period 0, the firm choses e_1 to maximize

$$\frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta} - \frac{(\mu v_h^2 + (1-\mu)v_l^2)(1+\alpha)}{4(1+\delta)} - \frac{e_1^2}{2}$$

Taking into account (1), this equals

$$\frac{(e_1+e_2)(\mu v_h^2 + (1-\mu)v_l^2)}{4\delta} - \frac{(e_1+e_2)(\mu v_h^2 + (1-\mu)v_l^2)(1+\alpha)}{4(1+\delta)} - \frac{e_1^2}{2} \tag{43}$$

Optimal e_1 equals:

$$e_1 = \frac{(1-\delta\alpha)(\mu v_h^2 + (1-\mu)v_l^2)}{4\delta(1+\delta)} \tag{44}$$

Miners chose e_2 to maximize:

$$\frac{p_1}{1+\delta} - \frac{e_2^2}{2} = \frac{(\mu v_h^2 + (1-\mu)v_l^2)(1+\alpha)}{4(1+\delta)} - \frac{e_2^2}{2}$$

Taking into account (1), this equals

$$\frac{(e_1+e_2)(\mu v_h^2 + (1-\mu)v_l^2)(1+\alpha)}{4(1+\delta)} - \frac{e_2^2}{2}$$

Optimal e_2 equals:

$$e_2 = \frac{(1+\alpha)(\mu v_h^2 + (1-\mu)v_l^2)}{4(1+\delta)}$$

(35) and (36) imply

$$e_1 + e_2 = \frac{\mu v_h^2 + (1-\mu)v_l^2}{4\delta}$$

It imply that (43) equals:

$$\frac{(e_1+e_2)(\mu v_h^2 + (1-\mu)v_l^2)}{4\delta} - \frac{(e_1+e_2)(\mu v_h^2 + (1-\mu)v_l^2)(1+\alpha)}{4(1+\delta)} - \frac{e_1^2}{2} =$$

$$= \frac{(1+2\delta-\alpha^2\delta^2-2\alpha\delta^2)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2}$$

And (44) equals

$$\frac{(e_1+e_2)(\mu v_h^2 + (1-\mu)v_l^2)(1+\alpha)}{4(1+\delta)} - \frac{e_2^2}{2} = \frac{(1+\alpha)(2+\delta-\alpha\delta)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta(1+\delta)^2}$$

When selling tokens, the entrepreneur's total profit is:

$$\Pi = p_0 + \frac{(1+2\delta-\alpha^2\delta^2-2\alpha\delta^2)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2}$$

subject to

$$p_0 = \frac{(1+\alpha)(2+\delta-\alpha\delta)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta(1+\delta)^2}$$

It implies

$$\Pi = \frac{(1+\alpha)(2+\delta-\alpha\delta)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta(1+\delta)^2} + \frac{(1+2\delta-\alpha^2\delta^2-2\alpha\delta^2)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2} =$$

$$= \frac{(1+4\delta+\delta^2+2\alpha\delta-2\alpha\delta^2-2\alpha^2\delta^2)(\mu v_h^2 + (1-\mu)v_l^2)^2}{32\delta^2(1+\delta)^2}$$

Optimal

$$\alpha = \frac{1-\delta}{2\delta}$$

And the entrepreneur's profit equals:

$$\Pi = \frac{3(\mu v_h^2 + (1-\mu)v_l^2)^2}{64\delta^2} \tag{45}$$