DECENTRALIZED UNDERWRITING

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Abstract

Insurance products can be optimized with emerging decentralized technology. We propose the use of cryptocurrencies as claims on future cash flows of an underwriting business operated by a Decentralized Autonomous Organization (DAO). The design of our DAO allows for decentralized collaboration (i) among DAO underwriters as well as (ii) between underwriters and consumers. In this decentralized system, the tokens essentially substitute for reputation. Financial distress or bankruptcy of an individual underwriter does not have to affect either customers or the DAO as the insurance contracts are backed by encumbered tokens. The structure of incentives embedded in the design has the potential to lower capital requirements and the related need for capital regulation.

***Key Words**:* Insurance, Underwriting, Finance, Token Models, Cryptocurrencies, Feedback Effects, Emerging Technology, Tokens, Blockchain, Distributed Ledger Technology

***JEL Categories**:* K20, K23, K32, L43, L5, O31, O32

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I. Introduction

The insurance and underwriting industries are subject to significant cost, inefficiencies, and barriers to entry. In the current system, insurance underwriting drives the insurance process and business. Underwriters protect insurance companies' books of business from risks and potential losses and issue insurance policies at a premium that is commensurate with the exposure presented by the risk. The cost of underwriting includes the cost incurred by insurance companies when determining whether to accept or decline an insurance contract and the associated risk. Given the nature of its business and the need for consumer protection, the insurance industry is subject to a high degree of capital requirements and the related need for capital regulation. Financial distress or bankruptcy of an individual underwriter affects consumers who may no longer be protected by the insurance contract and have to look for new coverage. Each insurance company applies its own set of underwriting guidelines to help the underwriter determine whether or not the company should accept the insureds. The insurance market is dominated by a few core players and subject to high barriers to entry for new market entrants. In the current system, democratized access to the underwriting process and collective decision making on risk does not exist.

The literature has started to evaluate emerging decentralized token models as means of optimizing the insurance business. Asset tokens already exist that directly or indirectly serve as claims on future output or profits. Proposals to operate DAOs in the insurance field have also already been put forward and are under active development. IAIS (2017) provides a survey of current and potential future impact of Fintech on new insurance products and the structure of the insurance industry. Marke (2018) contains an update relating to the B3i (Blockchain Insurance Industry Initiative), an initiative that was launched in 2016 by a consortium of international insurance companies with the goal of pilot-testing the blockchain for implementing highly complex reinsurance contracts. A report by Hogan Lovells (2017) contains not only an analysis of the legal and regulatory challenges involved in implementing the technology of the blockchain and smart contracts in the insurance industry, but also some examples of firms that have already started implementing some aspects of this technology.

In order to appreciate the innovative features of our proposal herein and the resulting potential benefits to both underwriters and consumers, it is important to develop an understanding of the proposed design of the DAO. The next section contains an outline.

II. The Design of the Underwriting DAO

The novelty of our proposal lies in the decentralized and democratized underwriting functionality enabled by our DAO design. The Underwriting DAO we propose consists of a group of underwriters, who roughly correspond to the partners or shareholders of an insurance company. These underwriters each hold a certain number of tokens in the DAO. We will refer to these tokens on occasion as reputation tokens as an agent's proportional holdings of these tokens is likely to increase over time only if the agent were to follow sound and successful underwriting practices.

It is important to note that the reputation tokens are separate and distinct from the cash currency that the insured use to pay their premia.

Reputation tokens serve multiple purposes.

- First, only token holders are allowed to participate in underwriting insurance policies. Inbuilt processes are used to assign new business to token holders. Policies may be underwritten either singly or jointly by these agents.
- Second, these tokens serve as claims on the future cash flows generated by the DAO. Insurance premia collected by the DAO are distributed among the token holders in proportion to their token holdings. It is worth emphasizing that the premium from a policy is not considered the revenue solely of the underwriters. Instead, the premia are treated as the revenue of the entire DAO and shared among the DAO participants. Thus, the value of the tokens is a function of the expected future cash flows of the DAO.

- Third, agents who underwrite policies by staking their reputation tokens are rewarded with a certain number of newly minted reputation tokens as salaries, based on a predetermined formula. Thus, the total number of tokens grows over time. This implies that "passive" agents who hold the tokens purely to receive a share of future premia will find their proportional ownership in the DAO decrease over time. Their income may however still increase if the overall revenues of the DAO grow at a sufficiently faster pace. Therefore, the effect of the design is to incentivize agents to play an active" role by participating in underwriting activities and thereby grow the business, while still allowing passive investors to derive income and speculate on growth.
- Fourth, the design requires the underwriters to "stake" or “encumber” an appropriate number of tokens against each policy they underwrite. These tokens in effect serve to secure the promises of the underwriters. The number of tokens to be encumbered is based on a preset formula with the objective of ensuring that the value of the encumbered tokens is sufficient to meet any claims that may arise at any point in the life of the policy. Such encumbered tokens continue to remain under the ownership of the respective agents and entitle the owners to receive their share of future premia. In case, there is no claim on the policy, the tokens are "freed up" or become "unencumbered" when the policy matures. In case the insured event were to occur during the life of the policy, the agents who underwrote the policy can (in effect) reclaim these tokens (or receive replacement tokens) after meeting the claim. However, the underwriters of the policy may choose not to reclaim the tokens. For convenience, this is referred to as a "breach" by the underwriters. In such a case, the encumbered tokens, along with additional freshly minted tokens as needed, would be sold in an auction. All current DAO participants as well as outsiders interested in joining the DAO may bid for the tokens in this auction. The objective here is to generate enough proceeds from the auction so as to meet the claim on the policy. Note that a breach by underwriters on a policy does not imply a default by the DAO. Under normal market conditions, a well-designed DAO should experience very few breaches, if any; and in case of a breach, the mechanism

outlined above should ensure that the customer suffers no losses on this insurance policy.

Under what circumstances would a breach occur? It would occur only if the underwriters concerned believed that the value of these tokens is less than the payment they need to make in order to reclaim the tokens. In general, this will happen only if there is a dramatic shift in the future prospects of the DAO, such as a sharp decrease in expected future revenues or a sharp increase in expected payments on outstanding policies.

III. Related Literature

There is a growing literature on cryptocurrencies, token designs, and token uses for funding start-up ventures. Bakos and Halaburda (2018) provide a good review as well as a study of the network effects of Initial Coin Offerings (ICOs). In their model, platform-specific tokens provide funding for capital constrained firms while giving early adopters the opportunity to benefit from the possible future success of the venture. In the process, the token issue also helps solve the coordination problem relating to network adoption. The focus of Li and Mann (2018) is similar in that their objective too is to show how ICOs can solve the coordination problem.

Recent studies that focus on valuation of tokens include Catalini and Gans (2018) and Cong et al (2018). In the former, the focus is on ICOs as an alternative to equity financing for new ventures and on the challenges of pricing an ICO when the value of a token depends on the highly uncertain future demand for the services provided by the platform. In the latter, the focus is on valuation of tokens in a dynamic, continuous time setting in which agents take into account both the utility value of the token as well as possible value appreciation in making their decision regarding their token holdings.

Malinova and Park (2018) compare ICOs to equity financing and also study the question of how best to structure a token offering. As in Catalini and Gans (2018), the objective of the token sale is to fund development and growth, effectively a trade-off of future revenue for current funding. The question of interest is whether the tokens should represent a claim on future revenue or output. Interestingly, they find that the optimal way to structure the token offering is as a combination. Structuring it as purely a claim on one or the other results in the monopolist entrepreneur either under-producing or over-producing and therefore, a sub-optimal project net present value.

The current study is related to these prior studies in that we too study the valuation and design of cryptocurrencies, token designs, and strategic decision-making by DAO participants, and the optimal structure of incentives. However, there are also several important differences between the studies mentioned above and the current one. The most important difference perhaps is that our focus is squarely on designing a DAO to conduct the business of underwriting. The focus is broader than may appear at first sight. By underwriting, we do not have in mind only traditional insurance policies, but a variety of use cases that may range from providing insurance to the Internet of Things (IoT) to guaranteeing settlements on online exchanges. In fact, almost any transaction on the blockchain that does not involve an exchange of purely digital tokens may require or benefit from underwriting. Another key difference is that in our study, the purpose of issuing tokens is not only to raise capital but also to provide the owners the opportunity and incentive to develop the business of the DAO. The focus is not on how the tokens help solve the coordination problem, but rather on how best to design the mechanism so as to provide utility and stability to all participants, both underwriters and consumers.

IV. Research Objectives and Questions

The main objectives of this paper are as follows:

- To develop a mathematical model in order to study optimal decision-making by the DAO, its steady-state performance, and the impact of possible shocks. In particular, the model will help determine the viability of the business model outlined above, shed light on potential weaknesses, and help assess its advantages and disadvantages as compared to a traditional insurance firm.

- To address specific questions such as the following:
  - What are the key variables that determine the DAO's decisions regarding how much premium to charge, how much risk to take, and how to reward underwriters?
  - How is the value of a token determined?
  - What are the circumstances and the likelihood of a breach by an underwriter, and the likelihood of the related but distinct possibility of the DAO facing financial distress?
  - How do the economic capital requirements of the DAO compare with that of a traditional insurance firm?
  - What kind of a governance structure should be put in place in order to make decisions relating to changes in protocol and, more generally, to handle unforeseen contingencies?

In sum, the paper will address questions relating to optimal design of incentives for DAO participants and safeguards to ensure that the design is fair and just as well as sustainable.

V. MODEL

A ≡ policy amount (maximum claim initially assumed to be actual payout)
N ≡ number of agents
S_t ≡ number of tokens at the end of the period (time step) t
M_t ≡ number of policies issued each period
p_t ≡ probability of a claim (occurrence of insured event) in any given period
τ ≡ policy duration (number of periods or time steps for which policy is active)
π ≡ premium per dollar of policy amount (paid up front)
ρ ≡ proportion of existing tokens given out as reward per policy. We assume that every policy issued in a given period receives the same number of reward tokens. Thus, $S_t = S_{t-1}(1+\rho M_t)$.

$\gamma_t \equiv$ proportion of existing tokens given out as reward tokens in period t. Thus, $\gamma_t = \rho M_t$, and $S_t = S_{t-1}(1+\gamma_t)$.
$r \equiv$ discount rate
$V_t \equiv$ total value of DAO at the end of period t.

For simplicity, we will assume for now that:

- The DAO is in a steady state. This means that all the variables listed above, with the exception of S_t, are constant. In particular, M, the number of policies issued in a period, is constant although we will consider the case of a stochastic M in a later section.
- The actual number of claims each period is equal to the expected number of claims. Also, the expected number of claims each period will be assumed to be a whole number. Alternatively, we allow for partial claims on a policy. Thus, for example, if there are 100 policies outstanding and the probability of a claim on each of these policies is 2.5%, then we will assume that there are 2.5 claims in that period.
- All policies issued in a period receive the same number of reward tokens. Thus, the total number of tokens grows each period at a constant rate, γ. Reward tokens received in a period are entitled to a share of the premia received in that period, but can be first used to issue new policies only in the next period.

The probability of a claim (payout) on the policy at some point in the life of the policy τ is:

$$\sum_{t=1}^{\tau} p(1-p)^{t-1} = 1 - (1-p)^{\tau}$$

We assume that no claims can be made on a policy in the same period in which it is issued. The expected number of policies outstanding each period is:

$$M\sum_{t=1}^{\tau}(1-p)^{t-1} = \frac{M(1-(1-p)^{\tau})}{p}$$

The total potential liability on outstanding policies is therefore:

$$\frac{AM(1-(1-p)^{\tau})}{p}$$

The expected liability on outstanding policies can be calculated using the table below:

No. of periods to maturity	No. of policies	Probability of a claim at some point in policy's remaining life	Expected number of claims
τ	M	$1 - (1-p)^{\tau}$	$M(1 - (1-p)^{\tau})$
$\tau - 1$	$M(1-p)$	$1 - (1-p)^{\tau-1}$	$M(1-p)(1 - (1-p)^{\tau-1})$
$\vdots$			
1	$M(1-p)^{\tau-1}$	$1 - (1-p)$	$M(1-p)^{\tau-1}(1 - (1-p))$

Therefore, the total expected number of claims (at some point or other in a policy's life) on all outstanding policies in a given period is given by adding up the last column, which gives:

$$M(1+(1-p)+\cdots+(1-p)^{\tau-1}-\tau(1-p)^{\tau}) = M\left(\frac{(1-(1-p)^{\tau})}{p}-\tau(1-p)^{\tau}\right)$$

Therefore, the expected liability on outstanding policies is:

$$AM\left(\frac{(1-(1-p)^{\tau})}{p}-\tau(1-p)^{\tau}\right)$$

We reiterate that the above is the expected liability only on currently outstanding policies. It does not take into account policies issued in subsequent periods. The expected liability (cash outflow or payout) each period is:

$$\frac{pAM(1-(1-p)^{\tau})}{p} = AM(1-(1-p)^{\tau})$$

It is worth noting that the expected liability on the M policies issued in the current period is also given by the same expression as above, namely:

$$AM(1-(1-p)^{\tau})$$

1. Value of the DAO in Steady State

At any point in time, the value of the DAO as a whole is just the present value of all expected future cash flows. In steady state (i.e., with constant M and p), the value of the DAO as a whole can be easily calculated by discounting the constant expected cash flow each period. The cash inflow each period is Mπ. The expected cash outflow each period is given by the expression above. Therefore, the value of the DAO as at the start of the current period (*t = 0*) is given by:

$$\sum_{t=1}^{\infty}\frac{AM(\pi-(1-(1-p)^{\tau})}{(1+r)^{t}}=\frac{AM(\pi-(1-(1-p)^{\tau})}{r}$$

2. Value of Tokens in Steady State

Valuing tokens, even in steady state, is complicated for two reasons. Firstly, the number of tokens grows at rate γ. Secondly, the value of a token will depend on whether or not it is currently encumbered, and, among encumbered tokens, on the time period in which the token is expected to "free up" or become unencumbered (i.e., become available for encumbrance on new policies). In general, the sooner a token is expected to be released from encumbrance (by the policy on which it is staked terminating due to either a payout or reaching maturity), the greater its value.

For simplicity, we will assume that all unencumbered tokens available as of the start of a period will be staked on the new policies issued in that period even if a smaller number of tokens is sufficient to cover the maximum possible potential liability on these policies. (Given that the DAO is supposed to be in a steady state, the assumption is not unreasonable.)

For a given period t, let

> $n_{j,t} \equiv$ number of currently existing tokens (as at the end of period t) expected to be available for staking on a policy j periods hence, for $j = 1$ to $\tau + 1$. In particular, $n_{1,t}$ is the number of unencumbered tokens as at the end of period t that are available to be staked on new policies in period $t+1$.
> $v_{j,t} \equiv$ collective value as at the end of period t of the $n_{t,j}$ tokens for $j = 1$ to $\tau + 1$.

In steady state, for any given j, $v_{j,0} = v_{j,1} = v_{j,t}$ for all t. So for convenience, we can omit the second subscript. Further,

$$\sum_{j=1}^{\tau+1} n_{j,t} = S_t$$

In words, what we are doing here is the dividing up the total number of tokens in existence as at the end of period t into different groups based on when the tokens can be (expected to be) staked again. As at the end of period t, $n_{1,t}$ is the number of tokens that are unencumbered and hence can be staked on a new policy in the next period (i.e., one period hence). The remaining tokens that make up S_t are all currently (i.e., as of the end of period t) encumbered.

Another useful result is that

$$n_{1,t} = n_{2,t-1} + \gamma S_{t-1}$$

For now, we will assume that

- The process (DAO) is in a steady state: M, the number of policies issued in a period, and p, the probability of the event occurring in any single period, are both constant.
- The total number of tokens grows each period at a constant rate, γ.
- While the policy duration is fixed, policies are infinitely divisible as far as the amount is concerned.

Importantly, given the steady state assumption, values for variables such as future policy premiums, future claims and payouts, etc., will be treated as constants, even though strictly speaking these values are expectations.

For ease of exposition, we will value the tokens as of period *0* (or the beginning of period *1*). Note that $n_{1,0}$ is made up of tokens that were

- freed up in period 0 owing to either a payout on some policies (due to the occurrence of the insured event) or the maturing of some policies, or
- awarded as reward tokens in period 0 for issuance of new policies.

The value of these $n_{1,0}$ tokens, v_1, is based on

- share of premiums on all policies issued in $t \geq 1$
- value of tokens received as a reward in $t = 1$
- payouts on the new policies issued in $t = 1$
- value of these tokens as and when they free up in future periods (when the policies issued by staking these $n_{1,0}$ tokens either pay out or mature in periods *2* through $\tau + 1$.

The following table lays out the cash flows relating to the $n_{1,0}$ tokens:

Period	***Cash Flows***
1	$\pi AM\left(\frac{n_{1,0}+\gamma S_0}{S_1}\right)+\frac{\gamma S_0}{n_{1,1}}v_1$
⋮	⋮
t	$(1-p)^{t-2}\left(\frac{n_{1,0}}{S_t}\pi AM+p\left(\frac{n_{1,0}}{n_{1,t}}v_1-AM\right)\right)$
⋮	⋮
τ+1	$(1-p)^{\tau-1}\left(\frac{n_{1,0}}{S_{\tau+1}}\pi AM+p\left(\frac{n_{1,0}}{n_{1,\tau+1}}v_1-AM\right)\right)+(1-p)^{\tau}\frac{n_{1,0}}{n_{1,\tau+1}}v_1$

The value as of period *0* of these $n_{1,0}$ tokens, v_1 is the present value of the cash flows listed in the table. Collecting terms and solving for v_1, we get

$$v_1 = \frac{\frac{\pi AM}{(1+r)}\left(\frac{n_{1,0}+\gamma S_0}{S_1}\right) + \sum_{t=2}^{\tau+1}\frac{(1-p)^{t-2}}{(1+r)^t}\left(\frac{n_{1,0}}{S_t}\pi AM - pAM\right)}{1 - \frac{\gamma S_0}{(1+r)n_{1,1}} - \sum_{t=2}^{\tau+1}\frac{(1-p)^{t-2}}{(1+r)^t}p\,\frac{n_{1,0}}{n_{1,t}} - \frac{(1-p)^{\tau}}{(1+r)^{\tau+1}}\frac{n_{1,0}}{n_{1,\tau+1}}}$$

For convenience, we can write this more compactly as follows:

$$v_1 = \frac{\pi\Lambda_1 - p\Lambda_2}{\Lambda_3}AM$$

where

$$\Lambda_1 = \frac{1}{(1+r)}\left(\frac{n_{1,0}+\gamma S_0}{S_1}\right) + \sum_{t=2}^{\tau+1}\frac{(1-p)^{t-2}}{(1+r)^t}\frac{n_{1,0}}{S_t}$$

$$\Lambda_2 = \sum_{t=2}^{\tau+1}\frac{(1-p)^{t-2}}{(1+r)^t}$$

$$\Lambda_3 = 1 - \frac{\gamma S_0}{(1+r)n_{1,1}} - \sum_{t=2}^{\tau+1}\frac{(1-p)^{t-2}}{(1+r)^t}p\,\frac{n_{1,0}}{n_{1,t}} - \frac{(1-p)^{\tau}}{(1+r)^{\tau+1}}\frac{n_{1,0}}{n_{1,\tau+1}}$$

The design of the DAO requires that v_1 should be large enough to cover the maximum possible liability on the M policies against which these tokens are to be encumbered. We will later derive a condition on the premium π to ensure this.

Let η denote the proportion of the expected number of tokens available for encumbrance to the total number of tokens:

$$\eta \equiv \frac{n_{1,t}}{S_t}$$

In steady state, this ratio will be constant and therefore, we do not need a time subscript for η. Further, as S_t grows at a constant rate γ, so too will $n_{1,t}$.

In order to find η, we start by noting that $n_{1,0}$ is the sum of three components: (i) reward tokens received in period *0*, (ii) tokens freed up from policies that matured in period *0*, and (iii) tokens freed up from claims that occurred in period *0*. Thus,

$$n_{1,0} = \gamma S_{-1} + (1-p)^{\tau}\eta S_{-(\tau+1)} + \eta \sum_{t=2}^{\tau+1} p(1-p)^{t-2} S_{-t}$$

Using the relationships $S_t = S_0(1+\gamma)^t$ and $n_{1,0} = \eta S_0$, and assuming that $\gamma > 0$, we can solve the above equation for η:

$$\eta = \frac{\gamma(1+\gamma)^{-1}}{1-(1-p)^{\tau}(1+\gamma)^{-(\tau+1)} - p\sum_{t=2}^{\tau+1}(1-p)^{t-2}(1+\gamma)^{-t}}$$

$$= \frac{\gamma(1+\gamma)^{\tau}}{(1+\gamma)^{\tau+1} - (1-p)^{\tau} - p\sum_{t=2}^{\tau+1}(1-p)^{t-2}(1+\gamma)^{\tau+1-t}}$$

In order to compute v_1, we take S_0 as given, compute S_t for each t using $S_t = S_0(1+\gamma)^t$, compute η (which is a function only of p and γ), and then compute $n_{1,t}$ for each t using $n_{1,t} = \eta S_t$.

Next, we calculate v_2, the value of the $n_{2,0}$ set of tokens – namely the tokens that are expected to free up in the next period and be available for encumbering in two periods. We begin by noting that, in steady state, holders of the $n_{2,0}$ set of tokens can collectively expect the same pattern of cash flows as the holders of the $n_{1,0}$ set of tokens except that: (i) the cash flows would be shifted forward by one period; and (ii) as the $n_{2,0}$ set of tokens are currently encumbered, the holders will face some additional cash flows in the next period – namely, cash inflows from premiums on new policies and cash outflows from payouts in period *1*. Note that the tokens freed up from all policies that either pay out or mature in $t = 1$ belong by definition to the $n_{2,0}$ set of tokens. Therefore,

$$v_2 = \frac{n_{2,0}}{n_{1,1}} \frac{v_1}{(1+r)} + \frac{1}{(1+r)} \left(\frac{n_{2,0}}{S_1} \pi AM - pAM \frac{(1-(1-p)^\tau)}{p} \right)$$

In calculating v_2 above, we keep in mind that

$$n_{1,1} = \eta S_1 = \eta S_0 (1+\gamma)$$

Similarly, other than the time-shifted cash flows of value v_1, the cash flows to the holders of the $n_{3,0}$ set of tokens (assuming that $\tau \geq 2$) consist of (i) their share of premiums from new policies and (ii) the payouts in period 2, but keeping in mind that a portion of this payout relates to new policies issued in $t = 1$ for which they are not liable:

$$\begin{aligned} v_3 = \frac{n_{3,0}}{n_{1,2}} \frac{v_1}{(1+r)^2} &+ \frac{1}{(1+r)} \frac{n_{3,0}}{S_1} \pi AM \\ &+ \frac{1}{(1+r)^2} \left(\frac{n_{3,0}}{S_2} \pi AM - pAM \frac{(1-(1-p)^\tau)}{p} \right. \\ &\left. + pAM \right) \end{aligned}$$

In calculating v_3 above, we use the result that

$$n_{1,2} = \eta S_2 = \eta S_0 (1+\gamma)^2$$

In general, for $t = 3$ through $\tau + 1$ (assuming that $\tau \geq 2$),

$$\begin{aligned} v_t = \frac{n_{t,0}}{n_{1,t-1}} \frac{v_1}{(1+r)^{t-1}} &+ \sum_{k=1}^{t-1} \frac{1}{(1+r)^k} \frac{n_{t,0}}{S_k} \pi AM \\ &+ \frac{1}{(1+r)^{t-1}} \left(-pAM \frac{(1-(1-p)^\tau)}{p} \right. \\ &\left. + pAM \sum_{k=0}^{t-3} (1-p)^k \right) \end{aligned}$$

We reiterate that in the expression above, we are taking the current period to be 0, and thinking of v_t as the value of the $n_{t,0}$ set of tokens that are expected to become unencumbered in period $t - 1$ and therefore available for staking on new policies in period t. The last term in the expression above pertains to payouts on policies issued in periods *1* through $t - 2$, i.e., in periods subsequent to the current period, and therefore liabilities that attach not to the holders of the $n_{t,0}$ set of tokens, but rather to the holders of the $n_{1,0}$ set, $n_{2,0}$ set, and so on. (For instance, policies issued in period *1* are related to the $n_{1,0}$ set. Therefore, in our calculations above, the payouts on those policies are included in v_1. Similarly, policies issued in period *2* are related to the $n_{2,0}$ set, and therefore, the payouts on those policies are implicitly included in v_2 (in the first term), and so on. The key point is that in valuing the $n_{t,0}$ set of tokens, the payouts on policies issued in periods *1* through *t-1* should not be included. For each $n_{t,0}$ set of tokens , we should only include payouts in period *t-1* on policies issued prior to period 1 to which these tokens have been encumbered. The sum of the values of the $\{n_{t,0}\}$ sets of tokens must of course equal the value of the DAO as a whole.

As mentioned previously, the design of the DAO requires that the value of the tokens staked against a policy should cover the maximum possible liability on the policy. Note that as the total number of tokens is growing at a rate of ρ per period, the value of individual tokens will depreciate over time.

Let m denote the "margin" or "markup" defined as follows:

$$m \equiv \pi - (1 - (1 - p)^{\tau})$$

Thus, m is the amount of premium per dollar in excess of the probability of a claim on the policy sometime during its life.

We ask the question, what is the minimum margin that will ensure that the following condition is satisfied:

$$\frac{v_1}{(1 + \gamma)^{(\tau+1)}} > AM$$

Using our previously derived expression for v_1, the condition on m works out to be the following:

$$m > \frac{(1 + \gamma)^{\tau+1}\Lambda_3 + p\Lambda_2 - (1 - (1 - p)^{\tau})\Lambda_1}{\Lambda_1}$$

3. *DAO Insolvency*

The DAO will be insolvent if the value of the DAO becomes negative - in other words, if the Present Value (PV) of expected cash flows from new policies is less than the expected cash outflow from currently outstanding (old) policies. If the DAO is insolvent, the value of a token will be negative.

One reason the DAO may become insolvent is if the number of policies expected to be issued each period, M_t, falls sharply.

Thus far, we have assumed that the DAO is in a steady state, and thus that M is constant. In this section, suppose that M_t follows a random walk.

$$M_t = M_{t-1} + \varepsilon_t$$

Above, ε_t is white noise, and $E_t\left(M_{t+k)}\right) = M_t$ for all $k \geq 0$ and t. Each M_t is known at the start of period t.

We take the current period to be 0, and our objective is to value the DAO as at the end of period 0 based on expected cash flows in period 1 and beyond. Let us break up the value of the DAO into two parts: (i) the steady state value based on the current level of policy issuance M_0, and (ii) an adjustment for the differences between this steady state value and the actual numbers of policies issued prior to the current period.

We note for future reference that for $t > 0$,

$$M_{-t} = M_0 - (\varepsilon_0 + \varepsilon_{-1} + \cdots + \varepsilon_{-(t-1)})$$

The key here is to calculate the expected cash payouts on policies issued prior to the current period ($t \leq -1$). The table below lays out the number of outstanding policies (on which claims can occur) as of each future period from 1 to $\tau - 1$.

Period	Number of outstanding policies (on which claims are possible)

1	$M_0 + M_{-1}(1-p) + \cdots + M_{-(\tau-1)}(1-p)^{\tau-1}$
2	$M_1 + M_0(1-p) + \cdots + M_{-(\tau-2)}(1-p)^{\tau-1}$
$\vdots$	
$\tau - 1$	$M_{\tau-2} + M_{\tau-3}(1-p) + \cdots + M_{-1}(1-p)^{\tau-1}$

Above, the table ignores periods τ and beyond as only up to period τ-*1* will there be any policies outstanding that were issued prior to the current period. All policies outstanding in these periods will have been issued in period *0* and later. In each period $t \geq \tau$, the number of outstanding policies is given by the same formula as the one for the steady state:

$$\frac{M_0(1-(1-p)^\tau)}{p}$$

We now make use of our martingale assumption for future values of M_t and re-express the information in the table above in terms of the shocks (or residuals or errors) ε_t.

Period	**Expected number of outstanding policies (on which claims are possible)**
1	$M_0((1-p)+(1-p)^2 \ldots + (1-p)^{\tau-1}) - \varepsilon_0(1-p) - (\varepsilon_0 + \varepsilon_{-1})(1-p)^2 - \cdots - (\varepsilon_0 + \varepsilon_{-1} + \cdots + \varepsilon_{-(\tau-2)})(1-p)^{\tau-1}$
2	$M_0((1-p)+(1-p)^2 \ldots + (1-p)^{\tau-1}) - \varepsilon_0(1-p)^2 - (\varepsilon_0 + \varepsilon_{-1})(1-p)^3 - \cdots - (\varepsilon_0 + \varepsilon_{-1} + \cdots + \varepsilon_{-(\tau-3)})(1-p)^{\tau-1}$
$\vdots$	
$\tau - 1$	$M_0((1-p)+(1-p)^2 \ldots + (1-p)^{\tau-1}) - \varepsilon_0(1-p)^{\tau-1}$

As defined in the previous section, m denotes the "margin" or "markup" defined as follows:

$$m \equiv \pi - (1-(1-p)^\tau)$$

As previously mentioned, the value of the DAO, V_0, can be broken up into two parts: (i) the steady state value based on the current level of policy issuance M_0, and (ii) an adjustment for the differences between this steady state value and the actual numbers of policies issued prior to the current period:

$$V_0 = \frac{mAM_0}{r} + adjustment\ relating\ to\ policies\ issued\ in\ periods\ -1\ through\ -(\tau-1)$$

$$= \frac{mAM_0}{r} + pA\left[\varepsilon_0 \sum_{k=1}^{\tau-1} \frac{(1-p)^k}{(1+r)^k} + (\varepsilon_0 + \varepsilon_{-1}) \sum_{k=1}^{\tau-2} \frac{(1-p)^{k+1}}{(1+r)^k} + \cdots + (\varepsilon_0 + \varepsilon_{-1} + \cdots + \varepsilon_{-(\tau-2)}) \frac{(1-p)^{\tau-1}}{1+r}\right]$$

For convenience, define α as follows:

$$\alpha \equiv \frac{1-p}{1+r}$$

The value of the DAO in period *0* can then be expressed as

$$= \frac{mAM_0}{r} + pA\left(\varepsilon_0 \sum_{k=1}^{\tau-1} \alpha^k + (\varepsilon_0 + \varepsilon_{-1})(1-p) \sum_{k=1}^{\tau-2} \alpha^k + \cdots + (\varepsilon_0 + \varepsilon_{-1} + \cdots + \varepsilon_{-(\tau-2)})(1-p)^{\tau-2}\alpha\right)$$

$$= \frac{mAM_0}{r} + pA\left(\varepsilon_0 \frac{\alpha(1-\alpha^{\tau-1})}{(1-\alpha)} + (\varepsilon_0 + \varepsilon_{-1})(1-p)\frac{\alpha(1-\alpha^{\tau-2})}{(1-\alpha)} + \cdots + (\varepsilon_0 + \varepsilon_{-1} + \cdots + \varepsilon_{-(\tau-2)})(1-p)^{\tau-2}\alpha\right)$$

Thus, the value of the DAO will be negative in period *0* if

$$\frac{mAM_0}{r} < -pA\left(\varepsilon_0 \frac{\alpha(1-\alpha^{\tau-1})}{(1-\alpha)} + (\varepsilon_0 + \varepsilon_{-1})(1-p)\frac{\alpha(1-\alpha^{\tau-2})}{(1-\alpha)} + \cdots + (\varepsilon_0 + \varepsilon_{-1} + \cdots + \varepsilon_{-(\tau-2)})(1-p)^{\tau-2}\alpha\right)$$

If the ε_t are negative and sufficiently large in magnitude, then the above condition will hold.

For a special case, suppose that $\varepsilon_t = 0$ for all $t < 0$. In words, suppose that M was constant until $t = -1$, and there is a one-time change in M at $t = 0$. The above condition simplifies to:

$$\frac{mM_0}{pr} < -\varepsilon_0 \frac{\alpha}{1-\alpha}\left((1-\alpha^{\tau-1}) + (1-p)(1-\alpha^{\tau-2}) + \cdots + (1-p)^{\tau-2}(1-\alpha)\right)$$

Thus, if ε_0 is sufficiently negative and large in magnitude (i.e., if there is a sufficiently large decrease in M), then the value of DAO will become negative and the DAO will become insolvent. Of course, a remedial course of action that could perhaps be taken in period *0* is to increase the margin m if that is possible. However, we would need to consider the impact of an increase in the margin on future demand.

4. Capital Requirements

We will use a simple, single-period model to illustrate how the DAO structure may reduce capital requirements – i.e., reserves needed to meet the unexpected component of payouts. In a traditional corporate structure, the insurance firm is a separate entity, and the amount of capital needed is a function of the standard deviation of total payouts. In the proposed DAO structure, assuming that there is a good system in place to ensure that an adequate amount of tokens are encumbered for each underwritten policy, each agent is responsible for meeting the payouts on the policies they have underwritten. Consequently, the burden of maintaining adequate capital falls on each individual agent, and the amount of capital that each agent will need (or find it prudent) to hold will depend on how much additional risk the potential underwriting liabilities contribute to the agent's overall portfolio. As a result, it is possible that the sum of the individual amounts of capital held by the DAO agents may be less than the amount of capital required to be held by a traditional corporate entity.

In the exposition below, we will assume for simplicity that all policies and agents are identical. Let

$N \equiv$ number of agents

$x_i \equiv$ the (random) payout of an individual agent i at the end of the period. The x_i are iid (independently and identically distributed), and therefore uncorrelated with each other.

$\sigma_x \equiv$ standard deviation of x_i

$y_i \equiv$ the (random) end-of-period value of the private portfolio of agent i, not including the payout. The y_i are iid and uncorrelated among themselves as well as with the x_i

$\sigma_y \equiv$ standard deviation of y_i

Suppose that the N agents are organized as a traditional firm. The capital requirement of the firm would be proportional to $\sqrt{N}\,\sigma_x$, the standard deviation of the total end-of-period payout. Under the DAO structure, the standard deviation of the value of each agent's overall portfolio (consisting of her private portfolio plus the payout on policies she has underwritten) would be $\sqrt{\sigma_y^2 + \sigma_x^2}$. The additional risk to the agent by the insurance payouts is therefore

$$\sqrt{\sigma_y^2 + \sigma_x^2} - \sigma_y$$

and each agent would hold capital proportional to this amount. The total amount of capital that the *N* agents combined would hold would therefore be proportional to *N* times this amount.

We see that

$$N\left(\sqrt{\sigma_y^2 + \sigma_x^2} - \sigma_y\right) < \sqrt{N}\,\sigma_x$$

if

$$\sqrt{\sigma_y^2 + \sigma_x^2} - \sigma_y < \frac{\sigma_x}{\sqrt{N}}$$

Thus, to reiterate the main point, if the incremental risk to the private portfolios of the agents from the contingent liabilities is small enough, the sum of the individual amounts of capital the DAO agents will hold will be less than the capital requirement for a traditional corporate entity.

VI. Conclusion

We conclude the paper with a summary of the key points.

The DAO structure we propose can be used by traditional insurance companies as well as niche players specializing in a narrow range of specialty policies. In common with all applications of the DAO concept, insurers as well as consumers can enjoy the benefits of transparency, efficiency and cost-effectiveness. In addition, the particular design outlined above is likely to facilitate the entry of new players to the insurance market. It is possible for a DAO to allow the participation of non-traditional firms and even individual investors. Such participants could buy tokens when they come up for auction, and then use these tokens to participate in underwriting, or else, just hold the tokens as a passive investment.

The design allows for collaboration (i) among DAO underwriters as well as (ii) between underwriters and consumers. The need to trust is minimized by appropriately designed economic incentives. The governance rules of the DAO can be set up so as to ensure that minority token holders are appropriately protected. In general, assuming all agents are active underwriters, the rules can be designed to ensure that the proportion of policies written by an agent in the long run is commensurate with the proportion of the agent's token holdings. Further, bad business decisions by one underwriter need not impact the other underwriters or the DAO. If a certain underwriter makes the mistake of underestimating the risk of the insured event, the losses will be suffered purely by the underwriter as long as the value of the staked or encumbered tokens covers the claim. As far as consumers are concerned, potential claims are fully backed or secured by the underwriters' encumbered tokens. In this decentralized system, the tokens essentially substitute for reputation. Even if the underwriters of a particular policy were to breach the contract, the auction of the encumbered tokens and the sale of additional tokens as needed ensures that the policy holder's claim is fully met. Thus, what we are referring to as a breach on a particular insurance contract does not necessarily imply any losses for the consumer.

The structure of incentives embedded in this design has the potential to substantially lower capital requirements and the related need for capital regulation. We note that the burden of maintaining sufficient liquidity in order to meet claims is not on the DAO, but rather on the individual underwriters that make up the DAO. Each underwriter would of course need to maintain sufficient liquidity and economic capital in order to be able to reclaim tokens as and when claims occur. (By economic capital, we mean the buffer that needs to be maintained in order to meet "unexpected" losses - i.e., losses in excess of the expected level.) However, it is possible under certain conditions that the total amount of capital that these agents will collectively hold is lower under this design than if the burden of meeting the liability were to be on a traditional insurance firm. This result is based on the premise that the amount of capital each underwriter will hold will be based on the risk of the underwriter's overall portfolio. The overall portfolio of an individual underwriter, especially a non-traditional one, may benefit from the addition of underwriting due to diversification, as attested to some extent by the existence of insurance-linked securities such as catastrophe bonds. As a result, the sum of the incremental VaRs (Value at Risk amounts) of the individual underwriters may be less than the VaR of an insurance firm that has underwritten the same contracts.

More importantly, how much capital an underwriter holds is a matter of their personal risk preference. An underwriter who is willing to tolerate fluctuations in their token holdings need only provide for expected losses. The key point is this: from the viewpoint of consumers and regulators, the encumbered tokens (which as we know derive their value from the DAO's future cash flows) essentially serve as a substitute for capital. Financial distress or bankruptcy of an individual underwriter does not have to affect either consumers or the DAO. As mentioned previously, in case of a breach on a particular contract, the policy holder’s claim can still be met by an auction of the encumbered tokens. Additional resources if required can be raised by minting new tokens. Barring highly adverse market conditions, the availability of "capital on tap" protects the DAO from default and bankruptcy. Thus, the design has the potential to greatly simplify capital regulation.

In sum, many of the innovative features of this design stem from the fact that the tokens serve multiple purposes: as reward for risk-taking, and a substitute for reputation and capital.

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