Raising capital under demand uncertainty*

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Abstract

Does security-based crowdfunding create economic value, and how? Which economic participants would find this method of financing attractive? What is the optimal capital raising process in security-based crowdfunding platforms? To answer these questions, we study the capital raising problem of an entrepreneur of an innovative project, when future demand is uncertain and market participants have access to costly and imperfect information. Under the optimal contract, investors take their backing decisions sequentially and financing goes through only if enough investors back the project. We show that if the ability of economic participants to commit is limited, raising capital via a security-based crowdfunding platform can alleviate under-financing of creditworthy projects.

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1 Introduction

A recent phenomenon in early-stage financing of innovative projects is security-based crowdfunding (CF). Although the first crowdfunding platforms (CFPs) started less than 10 years ago, the capital raised in 2015 reached \$10 billion, whereas the estimate of the size of the addressable market exceeds \$1.2 trillion.[1] CF differs significantly from the traditional methods of raising early-stage financing. A critical distinction is that a project's creditworthiness is determined exclusively by a mass of individuals who might be lacking expertise in evaluating investment opportunities. Another difference is that the capital raising process is facilitated by an online platform. These unique characteristics of CF imply that applying the insights of the conventional methods of financing to CF is not straightforward. Thus, there is a set of questions which arises naturally. For example, does CF create economic value, and how? Which agents would find this method of financing attractive? What is the optimal capital raising process in CFPs? We aim to shed light on these questions.

What lies at the heart of this paper is that demand uncertainty, which characterizes innovative products, can be alleviated by potentially informed market participants. Consequently, an entrepreneur could utilize positive information generated by the market to improve her financing terms. However, for market participants who lack the relevant expertise, acquiring information is costly, and the extent of their learning is rather marginal. Besides, the decision to acquire information involves information complementarities, which can be responsible for herding or free-riding incentives that hurt information production. Motivated by these remarks, we study the capital raising problem by highlighting the importance of designing a contract that efficiently aggregates information. Our findings are consistent with Mollick and Nanda (2015), who provide evidence that crowdfunding can aggregate information and alleviate under-financing. Also, we show that the optimal capital raising process is similar to the one observed in CFPs, featuring sequential backing decisions by potential investors and an All-or-Nothing financing rule. Finally, the present paper indicates that CFPs have a compar-

[1] *The Future of Finance - The Socialization of Finance* (Goldman Sachs, 2015). The size of the addressable market is based on the combination of the most popular sources of funding for small business owners, such as bankcard loans, home equity loans, venture capital, and angel investors.

ative advantage in innovative projects, and can be particularly attractive to startups and less experienced investors who might be lacking commitment power.

We develop a model which consists of two types of risk-neutral players: an entrepreneur and a mass of investors. The entrepreneur is cashless and seeks capital to finance a project. The return of investing in the project depends on the future demand, which can be high or low, but it is ex-ante uncertain. We allow investors to have access to a costly and imperfect signal about future demand, which can be with good or bad. Both the action of acquiring a signal and the signal realization is the investor's private signal. We focus on the case where the project becomes creditworthy as long as at least $k > 1$ good signals are observed. The underlying rationale is two-fold. First, it captures the idea that consumers are ex-ante reluctant to adopt new products (status-quo bias). Second, it reflects the idea that the information each individual has is marginal. The latter allows us to shed light on information complementarities among investors, and explore the implications for the capital raising process. In this setting, we characterize the contract which maximizes the entrepreneur's expected profits.

Under the optimal contract, the backing decisions are taken sequentially and financing goes through only if enough positively informed investors *back* the project.[2] Otherwise, the capital raising process is terminated with the entrepreneur not raising any funds, i.e., the contract exhibits an All-or-Noting (AON) feature. The sequential feature, which arises endogenously, allows the entrepreneur to use positive information produced by early investors to motivate late investors (*beliefs boosting channel*), whereas the AON feature allows the entrepreneur to use positive information produced by late investors to motivate early investors (*insurance channel*). The former is true because investors find it suboptimal to gather costly information if they are very pessimistic about the project's opportunities; the latter is true because the AON feature ensures that the project is financed only if enough positive information is produced. A critical insight of the paper is that if access to information is costly, learning from peers might help instead of hurt information production.

Our study highlights that adopting an AON feature is not a panacea; AON can facilitate

[2] *Backing* means that an agent *commits* to finance the project as long as predetermined conditions, which are characterized in the contract, are fulfilled.

information production only if it is accompanied by the *right* target. Therefore, a critical feature of the optimal contract regards the number (target) of agents that need to back the project for it to be financed. We show that the target coincides with the minimum number k of good signals required for the project to be creditworthy. If the target is higher than k, each individual investor would have an incentive to free-ride on her peers' information, which would increase the cost of incentivizing information production and/or lead to information acquisition breakdown. In contrast, if the target is lower than k, the project never becomes creditworthy, thus no one is willing to invest, let alone acquire information.

The final feature of the optimal contract is that early-backers should be rewarded. Compared to late-backers, early-backers are more pessimistic about the project's potential. Therefore, they need to be compensated by being offered a higher stake if the project is actually financed. One way of implementing this feature is by allowing early-backers to finance a larger part of the, conditional on financing, positive NPV project.

The second part of the paper refers to the implications of the model for security-based crowdfunding. A critical assumption in the main analysis regards the ability of both the entrepreneur and potential investors to commit. As we explain in Section 5, lack of commitment might lead to information acquisition breakdown. Therefore, our work indicates that entrepreneurs and investors with weaker commitment power would benefit from an intermediary party, such as a CFP, that can facilitate commitment. In a CFP, this is achieved by implementing an AON feature and by making investors' backing decisions binding. Thus, the present paper suggests that CFPs can create economic value not due to project screening, but due to overcoming individuals' lack of commitment. By overcoming lack of commitment, the CFP can create an environment that the market itself determines whether a project is creditworthy, which eventually leads to the financing of positive NPV projects that would not be financed otherwise. This channel is consistent with Mollick and Nanda (2015) who provide evidence that crowdfunding can play an important role by allowing projects to receive multiple evaluations and thereby lowering the incidence of "false negative".

The optimal contract produces a series of implications about the optimal design of the capital raising process in CFPs. First, potential investors shall take their backing decisions sequentially, and backing decisions shall be observable. Second, financing shall go through as long as a predetermined number of investors backs the project. Otherwise, the capital raising process shall be canceled. Third, investors who back the project earlier shall get better terms.

Apart from the implications for the platform design, this work indicates that CFPs can be particularly attractive to startups and less experienced investors who might be lacking commitment power. In addition, this work predicts that CFPs have a comparative advantage in innovative projects, for which demand uncertainty is more severe and information production is more valuable. As we discuss in Section 5, the aforementioned features of the optimal contract and the generated implications regarding the type of economic agents involved are consistent with the capital raising process in CFPs.[3]

The outline of the paper is as follows. Section 2 discusses how this work contributes to the related literature. Section 3 introduces the model. Section 4 provides the analysis and the main findings. Section 5 explores the link with CFPs. Section 6 discusses and concludes.

2 Related Literature

This paper pertains to the literature which studies contracts which incentivize information production and disclosure by experts, along with the lines of Gromb and Martimort (2007) and Inderst and Ottaviani (2009). We contribute to this literature in two directions. First, we explore the case where the information of individuals is marginal, and focus on how learning from peers affects individuals' incentives to gather and communicate information.[4] Second, in our setting the principal is a cashless entrepreneur, thus, is restricted to offering contracts which are contingent on the firm's performance.

As we develop a setting where backing decisions are taken sequentially, this paper relates to the literature on herding and information cascade, following the seminal papers of Banerjee

[3]The report *The Future of Finance - The Socialization of Finance* (2015) by Goldman Sachs provides a review of the crowdfunding industry, capturing the type of projects that have raised capital via CFPs and the type of investors involved in crowdfunding.

[4]A setting with information complementarities is also studied in Biais and Perotti (2008).

(1992), Welch (1992), Bikhchandani, Hirshleifer, and Welch (1992), and Smith and Sørensen (2000). The departure from the setting explored in these papers is four-fold. First, the agents are not endowed with private information, and information acquisition is costly. A critical property of costly information is that learning from peers might, in fact, help instead of hurt information production. Second, the order the agents take their backing decisions is endogenously determined by the contract. Third, in our setting, each agent's payoff is realized *after* all agents take their decision. This is a critical difference which implies that each agent affects *and* get affected by the actions of the agents that follow them. This feature also differentiates us from the literature on experimentation in a dynamic setting such as Glazer, Kremer, and Perry (2015). Fourth, in our setting, there is a principal whose implicit goal is to gather and communicate information. This is also true in Glazer et al. (2015). Finally, herding incentives are also studied by Åstebro, Fernández Sierra, Lovo, and Vulkan (2017) who provide empirical support of rational herding in security-based crowdfunding.

This paper relates to the security design literature when potential investors have access to relevant information. Therefore, our setting is close to Axelson (2007) and Axelson and Makarov (2016), but as opposed to these studies, information acquisition is costly. Also, similar to our paper, in Axelson and Makarov (2016) the entrepreneur approaches investors sequentially but, in our setting, the project is financed by multiple investors. This allows us to shed light on the information complementarities between investors, and explore the dynamics of the problem.

This paper also relates to the strand of the literature which highlights that investors might have access to relevant and costly information. A similar setting is studied in Allen and Gale (1999) and in Boot and Thakor (1993). The main goal in these papers differs from the main goal of our study. The present paper aims to shed light on how to incentivize information aggregation. This differs from Allen and Gale (1999) who focus on the market versus intermediated finance, and Boot and Thakor (1993), who focus on why a firm would be interested in issuing multiple types of financial claims against its cash flows. The interaction between firms and informed market participants is also studied in Goldstein and Guembel (2008) and Bond, Edmans, and Goldstein (2012).

A key finding of our paper is that the optimal contract exhibits an AON feature. The idea that making a decision conditional on the decision of other agents has been studied before in different settings. For instance, Cornelli (1996) shows that providing the product conditional that there are many potential buyers could be optimal. However, the channel we explore is different. In Cornelli (1996), conditioning decreases the cost of production, whereas in our case conditioning provides insurance. More recently, Cong and Xiao (2019), building on Bikhchandani et al. (1992), show the critical implications of an AON feature by highlighting, similar to our paper, its insurance properties. In contrast with Cong and Xiao (2019), in our setting agents are not endowed with private information, but they have to be incentivized to gather costly signals. Thus, compared to Cong and Xiao (2019), we focus not only on the information aggregation, but also on the information production. Besides, we show that both the AON feature and the fact that backing decisions are sequential arise optimally as a solution to the capital raising problem.

Chemla and Tinn (2017), who focus on reward-based crowdfunding when potential backers are privately informed, show that an AON feature might alleviate the moral hazard problem. A similar setting is studied by Strausz (2017). We differ from the these two papers as we focus on the investment rather than consumption motives of the backers. Also, in our setting, the value of the underlying product/project is common to all backers and not backer-specific. Finally, information acquisition is costly, which allows us to capture the impact of an AON feature on free-riding incentives. Brown and Davies (2018), in a security-based crowdfunding setting, highlight the insurance properties of an AON feature and show that this feature might be responsible for investors backing the project even when having negative information. This negative externality of the AON feature arises in our setting as well, but the entrepreneur finds it optimal to prevent it. Besides, compared to Brown and Davies (2018) and Strausz (2017), in our work the AON feature arises endogenously as part of the optimal contract. A key difference compared to Brown and Davies (2018), Strausz (2017), and Chemla and Tinn (2017) is that we explore a setting where agents take their backing decisions sequentially rather than simultaneously, which is a fundamental characteristic of raising capital via a CFP. Apart from the fact that the sequential feature arises endogenously, focusing on a setting where agents move sequentially allows us to explore the dynamics in the agents' incentives to acquire information. Also, costly information acquisition and sequential decisions differentiate us from Li (2017).

Finally, this work relates to book-building in IPOs, following the spirit of Benveniste and Spindt (1989) and Benveniste and Wilhelm (1990). Apart from the different focus, our work explores an environment where information is costly and the backing decisions are observable to all agents involved.

3 Model

3.1 Model Description

Environment. We explore an environment which consists of a risk-neutral entrepreneur and a mass of risk-neutral investors. The entrepreneur is cashless and aims to raise I to finance an indivisible project. Once financed, the project generates a cash flow, R. The realized cash flow depends on the level of future demand, θ, which is either high ($\theta = H$) or low ($\theta = L$). If the future demand is high, the cash flow is $R = 1$, whereas if the future demand is low, the cash flow is $R = 0$. A key feature of the model is that the future demand is ex-ante unknown. Finally, both the entrepreneur and investors believe ex-ante that the future demand is high with probability p_0.

Information Technology. Investors have access to an information production technology. In particular, each investor, by incurring cost c, can acquire a signal σ. The signal is either good ($\sigma = \sigma_G$) or bad ($\sigma = \sigma_B$), where $Pr(\sigma = \sigma_G|\theta = H) \equiv s_G > s_B \equiv Pr(\sigma = \sigma_G|\theta = L)$, i.e., the realization of a good signal is more likely when the future demand is high than low.

Assumption 1: Both the signal acquisition and the signal realization is the investor's private information.

Assumption 2: Each investor can acquire up to one signal, whereas the project needs at least $k \geq 2$ *consecutive* good signals in order to have positive NPV, i.e., $p_k - I > 0$ and $p_{k-1} - I < 0$ where $p_k = Pr(\theta = G|\sigma_1 = \sigma_G, ..., \sigma_k = \sigma_G)$.[5]

The rationale behind Assumption 2 is two-fold. First, it captures the idea that the information each individual has is rather marginal.This feature allows us to shed light on information complementarities among investors, and explore the implications for the capital raising process. Second, Assumption 2 captures the idea that consumers are reluctant to adopt new products, thus, ex-ante, the project has negative NPV. This is consistent with the status-quo bias.

[5]Therefore, k is the minimum integer which satisfies $\frac{p_0 s_G^k}{p_0 s_G^k + (1-p_0) s_B^k} \geq I$.

Actions. The entrepreneur's only action is to design the contract offered to potential investors. Conditional on accepting a contract, each potential investor i decides whether to acquire information, and subsequently, whether to back the project, where $d_i = B_i$ denotes the decision of backing the project and $d_i = N_i$ the decision of not backing the project. It is critical to make the distinction between the term *backing* a project, and *investing* in a project. *Backing* a project means that an agent commits to invest in the project as long as predetermined conditions, which are characterized in the contract and determined below, are fulfilled. In contrast, *investing* in a project refers to that action of financing the project. Also, note that given that investors are risk-neutral, they would prefer either not to invest, or to invest the maximum amount feasible, which is determined by the contract.

Contracting. We start by exploring contracts which allow potential investors to move sequentially. We assume that before each agent takes her backing decision, she observes the backing decisions of all preceding agents. This assumption simplifies the exposition of the paper, but it is trivial to show that this behavior would arise in equilibrium.[6] In Section 4.4, we explore the case where potentially investors move simultaneously; the optimality of allowing potential investors to take their backing decision sequentially or simultaneously remains to be determined in equilibrium. In both regimes, we assume competitive markets where investor's outside option is normalized to zero and there is no time discounting. Consistently with the aforementioned assumption, we focus on take-or-leave-it contracts.

In the sequential setting, the history at period t, denoted as $\mathcal{H}_t$, reflects the backing decisions of the agents that moved in periods 1 to $t-1$. Besides, $\mathcal{H}$ denotes the set of all possible histories. In this environment, the contract consists of three components. First, the contract characterizes the set of histories under which the project is financed, which we denote as $\mathcal{H}'$. Second, for *each* history in the set $\mathcal{H}'$, the contract characterizes: i) the total equity distributed to the investors, denoted as $\alpha(\mathcal{H}')$; and ii) the amount that *each* agent invests in the project, denoted as $I(\mathcal{H}')$.

[6] In fact, the entrepreneur would always have an incentive to disclose the backing decisions of preceding agents, as they reflect positive information regarding the project's demand. This relates to the signaling component of the entrepreneur's action; in this environment, not revealing a backing decision is correctly interpreted as the preceding agent not backing the project.

Since backing decisions are taken sequentially, we allow the individual investments to depend on the time a backing decision was taken. Finally, we focus on contracts for which the equity per unit invested is constant.[7]

Another way to think of this contract is as a menu of contracts which are characterized by the same condition regarding the histories for which the project is financed, but different combinations of investment - time of backing. Following that, we allow investors to choose their most preferred combination. Based on the previous remarks, we can denote a contract C as:

$$C(\mathcal{FR}(\mathcal{H}),\ \alpha(\mathcal{H}'),\ \mathcal{I}(\mathcal{H}')).^{8}$$

where $\mathcal{FR}(\mathcal{H})$ is an indicator function which takes value 1 for the histories for which the project is financed, and zero otherwise. Therefore, $\mathcal{H}'$ is the set of histories for which $\mathcal{FR}(\mathcal{H}) = 1$. One example of a contract that aims to raise $I = 0.1$ could be contract C', where

$$C' = (\mathcal{FR}(\{B_1, B_2\}) = 1,\ \alpha(\{B_1, B_2\}) = 20\%,\ \mathcal{I}(\{B_1, B_2\}) = \{0.06, 0.04\})^{9}$$

which implies that the project is financed only when the agent who is expected to move first and the agent who is expected to move second decide to back the project. Given that, the first agent invests $I_1 = 0.06$ in exchange of 12% equity, and the second invests $I_2 = 0.04$ in exchange of 8% equity.[10]

Objectives. The objective of the entrepreneur is to maximize her expected profit:

$$\mathbb{E}[Pr(H_J)\mathcal{FR}(H_J)Pr(\theta = H|H_J)(1 - \alpha(H_J))|\Omega^{ent}]$$

where H_J denotes each possible history, i.e., every element in $\mathcal{H}$, and Ω^{entr} denotes the information set of the entrepreneur in period zero. In words, the entrepreneur's expected profit equals

[7]Alternatively, we could focus on contracts where agents invest the same amount, but they do not necessarily receive the same amount of equity. There two representations generate qualitatively similar results.

[8]Note that we do not exclude contracts where the project is financed for more than one histories. To fix ideas, one example could be a contract that determines that the project is financed when two or three consecutive agents decide to back the project. Therefore, the contract determines two values of equity, and two investment allocations, one for each history that leads to the implementation of the project.

[9]Also, $(\mathcal{FR}(\{B_1, N_2\}) = 0, \mathcal{FR}(\{N_1, B_2\}) = 0, \mathcal{FR}(\}N_1, N_2\}) = 0$.

[10]Note that each investor pays 0.02 per 1% of equity.

the sum of the probability of each history for which the project is financed multiplied by the project's expected value that accrues to the entrepreneur conditional on that history.

The objective of investor i is to maximize her expected utility reduced by the cost of acquiring information, if information is acquired:

$$\mathbb{E}[Pr(H_J)\mathcal{FR}(H_J)Pr(\theta = H|H_J)\frac{I_i(H_J)}{I}\alpha(H_J) - \mathbb{1}c|\Omega_i^{inv}]$$

where $\mathbb{1}$ equals 1 if information is obtained, and zero otherwise. Also, Ω_i^{inv} denotes the information set of agent i and $\frac{I_i}{I}$ is the share financed by agent i.

Timing. In the case where investors move sequentially, the timing of the game is determined, to a great extent, endogenously by the contract. However, certain steps are exogeneously determined. First, the entrepreneur offers a take-or-leave-it contract to potential investors who select their preferred combination of investment-time of backing. Then, the agent who, according to the contract, is supposed to move first decides whether to gather information and subsequently whether to back the project. Following that, the agent who is supposed to move second observes the backing decision of the previous agent and decides whether obtain information and in turn, whether to back the project. This sequence continues until all investors take their backing decisions. Consequently, as long as the terms of the contract regarding the project implementation decision have been fulfilled, the entrepreneur raises capital from the agents who backed the project. Finally, the outcome is realized and the payments take place.

Evidently, in the case where potential investors move simultaneously, when taking their information acquisition and backing decisions, they do not observe the backing decisions of the other agents. We explore this case in Section 4.4.

Equilibrium Concept. The equilibrium concept is *Perfect Bayesian Equilibrium*, where the entrepreneur and potential investors choose their corresponding actions in order to maximize expected profits/utility and equilibrium beliefs are consistent.

3.2 Model Implications

Before setting up the maximization problem, it is important to shed light on the key features of the entrepreneur's problem. First, note that when there is uncertainty about the future demand of the project, the entrepreneur can benefit from using positive information produced by the market participants, as it allows her to raise capital at better terms. Second, note that by Assumption 2, at least k good signals must be generated for the project to have positive NPV, which implies that, in equilibrium, investors (or a subset of them) need to gather costly information. However, by Assumption 1, neither the signal acquisition nor the signal realization is observable, thus the contract cannot be contingent on them. We show in the Appendix that the only way for a cashless entrepreneur to incentivize information production by market participants, is by making sure that they have enough skin in the game, which is achieved by offering them stake in the company. Therefore, the entrepreneur is interested in finding the most efficient way of providing incentives, which in turn allows her to finance the project by giving away less equity.

A critical feature of this setting is that, all else equal, there are three areas in the agents' beliefs with completely different implications for their incentives to gather information. This is captured in Lemma 1.[11]

Lemma 1: *If, all else equal, an agent is very pessimistic or very optimistic about the future demand, then it is not feasible to be incentivized to acquire information.*

The rationale of Lemma 1 follows. Suppose that $\underline{p}$ denotes the beliefs of an agent before the information acquisition decision is taken and $\tilde{p}$ the beliefs of the same agent after a good signal is observed. First, consider the case where an agent is ex-ante very pessimistic about the future demand i.e., $\underline{p} < \hat{p}$, such as the project is not creditworthy even if she observes a good signal. Therefore, for $\underline{p} < \hat{p}$, information acquisition is not pivotal, which implies that the agent has no incentive to gather information or to back the project.[12]

[11] A similar feature arises in Glazer et al. (2015).

[12] Note that information acquisition is pivotal when an action which is ex-ante sub-optimal, becomes optimal for some signal realizations.

Consider now the case where an agent is ex-ante very optimistic about the future demand i.e., $\underline{p} > \hat{\hat{p}}$, such as she believes that it is very unlikely to observe a bad signal. In this case, her best response is to back the project without acquiring information, as information acquisition is costly and very unlikely to be pivotal.

Finally, if the entrepreneur is neither too optimistic nor too pessimistic, i.e., $\underline{p} \in (\hat{p}, \hat{\hat{p}})$ then acquiring new information is likely to be pivotal. For this range of beliefs, incentivizing information acquisition is feasible, as long as its cost is not prohibitively large.

Returning to the question of how to efficiently incentivize the agents to gather information, Lemma 1 implies that allowing agents to learn good news from their peers could be beneficial. To see this, suppose that $\tilde{\tilde{p}}$ denotes the agent's beliefs after learning good news from her peers but before acquiring a signal. Learning good news from peers can motivate information production as long as $\underline{p} < \hat{p}$ and $\tilde{\tilde{p}} \in (\hat{p}, \hat{\hat{p}})$, i.e., when the agent becomes from very pessimistic moderately optimistic. On the other hand, learning good news from peers might give rise to free-riding motives, which undermine the agents' incentives to gather information. This is true when $\tilde{\tilde{p}} > \hat{\hat{p}}$ and $\underline{p} \in (\hat{p}, \hat{\hat{p}})$, i.e., when the agent becomes from moderately optimistic overly optimistic. Besides, an additional problem that the entrepreneur faces regards the design of a contract where information is communicated across agents. This is achieved by making the backing decision information sensitive.

3.3 Numerical Example

Before we characterize the optimal contract, we start by focusing on a simple numerical example. In this setting, we provide the optimal contract and shed light on its main features. To simplify the algebra, we assume that $p_0 = 0.3$, $s_G = 1$, $s_B = 0.5$, $c = 0.01$, and $I = 0.5$. Table 1 illustrates investors' beliefs and the corresponding NPV of the project for different signal realizations. Note that for the project to have positive NPV, at least two good signals must be realized. Also, the revelation of a bad signal implies that the NPV of the project is negative with certainty.

Beliefs that demand is high	NPV
$Pr(\theta = H \mid 1 \times \sigma = \sigma_G) = 0.46$	-0.04
$Pr(\theta = H \mid 2 \times \sigma = \sigma_G) = 0.63$	0.13
$Pr(\theta = H \mid 3 \times \sigma = \sigma_G) = 0.77$	0.27
$Pr(\theta = H \mid \sigma = \sigma_B) = 0$	-0.5

Table 1: Beliefs & NPV for $p_0 = 0.3$, $s_G = 1$, $s_B = 0.5$, $c = 0.01$, $I = 0.5$.

Claim 0: *Under the optimal contract: i) potential investors take their* ***backing decisions sequentially****; and ii) the project is financed as long as the* ***first two agents back the project****; otherwise, the entrepreneur does not raise any funds (****All-or-Nothing****). Finally, conditional on the project's financing, the first agent invests* $I_1 = 0.30$ *for* $\alpha_1 = 52\%$ *equity, whereas the second agent invests* $I_1 = 0.20$ *for* $\alpha_2 = 34\%$ *equity.*

In what follows, we provide the intuition behind each feature of the optimal contract; a more thorough analysis is presented in the next sections.

All-or-Nothing (AON). The optimal contract implies that the project is financed as long as the target of two agents backing the project is reached; otherwise the entrepreneur does not raise any funds. Suppose that there is no AON feature. Then, there would be a positive probability that the first agent will end up financing a negative NPV project, even if her private signal is good. This would be the case if one of the remaining agents observes a bad signal and decides not to back the project. Besides, if there is no AON feature, the first agent will end up financing a large part of a negative NPV project, but only a small part of a positive NPV project. This is true because an agent who observes a bad signal finds it suboptimal to back the project. Thus, the AON feature –combined with the target of two agents– provides *insurance* to the first investor, by guaranteeing that the project is financed as long as its NPV is positive. Being insured against the event of financing a negative NPV project incentivizes the first agent to gather information and to back the project when a good signal is observed.

Target of two agents. Note that for an AON feature to provide insurance, the number of agents who need to back the project cannot be smaller that two and cannot be larger than two. The former is true because otherwise the implemented project would correspond to negative

NPV. The latter is true because otherwise all agents would have an incentive to free-ride, i.e., back the project without being positively informed. The rationale is the following. Suppose, for instance, that the target is raised to three agents backing the project for it to be financed. If this is the case, then each investor would have an incentive to deviate unilaterally, i.e., to back the project without acquiring costly information, as the implemented project has positive NPV (equal to 0.13) even if only two good signals are observed.

Sequential backing decisions. The intuition is two-fold. First, allowing for sequential decisions enables the entrepreneur to use positive information from the first investor to motivate the second investor; conditional on the first agent backing the project, the second agent knows that an additional good signal would reveal a positive NPV investment opportunity, thus, acquiring information is valuable. Second, note that restricting agents to move simultaneously might give rise to over-production of information: if a bad signal is observed, then uncertainty is resolved, thus, any additional signal is socially wasteful. Therefore, acquiring information sequentially leads to a better allocation of resources.

Decreasing investment. Although moving sequentially is socially desirable, all agents have an incentive to wait for the others to move first. This free-riding incentive can results in an information acquisition breakdown. Thus, an agent needs to be compensated for moving first. On way of doing so, is by allowing early movers to invest more, which effectively enables them to have larger share of the -conditionally on being financed- positive NPV investment opportunity.

4 Analysis

This section explores the case where $s_G = 1$. Following that, a bad signal reveals that the project has negative NPV with certainty. Focusing on the case where $s_G = 1$ improves the tractability of the model without affecting the main findings qualitatively as long as the cost of gathering information is not prohibitively large.[13] In the Appendix, we discuss the case where this assumption is relaxed.

[13]Specifically, as long as $c \leq \frac{(s_B-1)(s_G-1)\left(I(p_0-1)s_B^k - Ip_0 s_G^k + p_0 s_G^k\right)}{p_0\left(-(s_G-1)s_B^k + s_B\left(s_G^k-1\right) - s_G^k + s_G\right) + (s_G-1)\left(s_B^k-1\right)}$.

Following the spirit of Grossman and Hart (1983), the characterization of the optimal contract consists of two steps. In the first step, we take the financing rule $\mathcal{FR}(\mathcal{H})$, i.e., the set of histories for which the project is financed, as given and characterize: i) the constrained optimal equity level, $\alpha^*(\mathcal{H}')$; and ii) the individual contributions for each agent, $\mathcal{I}^*(\mathcal{H}')$.[14] In the second step, we characterize the optimal financing rule $\mathcal{FR}^*(\mathcal{H})$, conditional on the constrained optimal contract characterized in the first step.

4.1 Step 1: Constrained Optimal Contract

The only way for the entrepreneur to facilitate gathering and communication of information is by offering a contract such as $x(\mathcal{H})$ agents find it optimal to first acquire information *and* second back the project only when observing a good signal. Offering a contract according to which the backing decisions are information sensitive allows agents to perfectly infer the preceding agents' private information by simply observing the past backing decisions. We allow $x(\mathcal{H})$ to be a function of history. For example, the entrepreneur could offer a contract which incentivizes the second agent to gather information only if the first agent chooses to back the project, i.e., $x(B_1) = 2$, and $x(N_1) = 1$. Lemma 2 provides a set of properties that should hold in equilibrium, which in turn allows us to restrict the feasible values of $x(\mathcal{H})$.

Lemma 2: *Under the constrained optimal contract:*

(i) *The entrepreneur prefers incentivizing the first x investors to gather information, as long as the $x - 1$ preceding investors back the project.*

(ii) *It is never optimal to raise capital from uninformed agents.*

Regarding part one, note that for $s_G = 1$, a non-backing decision of an informed investor is correctly associated with a bad signal, which resolves the uncertainty about the future demand.[15] Resolving uncertainty implies that the information production has no value, thus, consistently

[14] Recall that $\mathcal{FR}(\mathcal{H})$ is an indicator function which takes value 1 for the histories for which the project is financed, and zero otherwise. Also $\mathcal{H}'$ is the set of histories for which $\mathcal{FR}(\mathcal{H}_{\mathcal{J}}) = 1$.

[15] Note that if a good signal was not leading to a backing decision, the agent would not have an incentive to gather information in the first place.

with Lemma 1, motivating an agent to gather information is neither feasible nor optimal. We discuss in the Appendix that part one also holds when $s_G < 1$, as long as the cost of acquiring information is not prohibitively large.

Part two relates to idea that conditional on the financed project having positive NPV, the agents who benefit from investing in it should be the ones that incurred the cost of information acquisition. If uninformed agents are allowed to invest in the project, then the amount left to be distributed to the remaining claimants decreases, thus, the entrepreneur must give away more equity.

Based on Lemma 2, we can build the entrepreneur's maximization problem. For a *given* financing rule $\mathcal{FR}(\mathcal{H})$, denoted as $\bar{\mathcal{FR}}(\mathcal{H})$, the maximization problem is given by:

$$\underset{C(\bar{\mathcal{FR}}(\mathcal{H}),\ \alpha(\mathcal{H}'),\ \mathcal{I}(\mathcal{H}'))}{\text{Maximize}} \quad \mathbb{E}[Pr(H_J)\bar{\mathcal{FR}}(\mathcal{H})(H_J)Pr(\theta = H|H_J)(1-\alpha(H_J))|\Omega^{ent}]$$

s.t. for each $t = \{0, ..., x\}$:

$$\mathbb{E}\, U_t(back|\sigma = \sigma_G, \Omega_t) \geq \mathbb{E}\, U_t(no\ back|\sigma = \sigma_G, \Omega_t) \tag{1}$$

$$\mathbb{E}\, U_t(no\ back|\sigma = \sigma_B, \Omega_t) \geq \mathbb{E}\, U_t(back|\sigma = \sigma_B, \Omega_t) \tag{2}$$

$$\mathbb{E}\, U_t(signal|\Omega_t) \geq \mathbb{E}\, U_t(no\ signal\ \&\ back|\Omega_t) \tag{3}$$

$$\mathbb{E}\, U_t(signal|\Omega_t) \geq \mathbb{E}\, U_t(no\ signal\ \&\ no\ back|\Omega_t) \tag{4}$$

$$\mathbb{E}\, U_t(signal|\Omega_t) = max\{\mathbb{E}\, U_1(signal|\Omega_0), ..., \mathbb{E}\, U_t(signal|\Omega_0)\} \tag{5}$$

$$\text{For each } H_J \in \mathcal{H}',\ I_1 + ... + I_x = I \tag{6}$$

Constraints (1) and (2) refer to the post information acquisition incentives. In particular, (1) and (2) imply that conditional on being informed, the agent has an incentive to back the project only if a good signal is observed. As explained earlier, offering a contract for which the backing decision is information sensitive allows the entrepreneur to communicate the information produced by each agent to her peers. Constraints (3) and (4) incentivize the agent to gather information instead of acting without acquiring information, by taking into consideration the backing decision that she expects to take after information is acquired. In addition, constraint (5) guarantees that each agent is indifferent regarding the time her backing decision is taken. Finally, constraint (6) states that for each history for which the project is financed, the total contribution should equal to the level of capital the entrepreneur aims to raise, i.e., I.

It is worth highlighting that the entrepreneur chooses x only indirectly via the choice of $\alpha(\mathcal{H}')$, and $I(\mathcal{H}')$. Lemma 3, that builds on Lemma 2, sheds light on the value of x that the entrepreneur wishes to implement under the optimal contract.

Lemma 3: *The entrepreneur finds it optimal to incentivize the first $x = k$ agents to gather information and back the project only when observing a good signal, as long as the $k-1$ preceding agents back the project.*

Proof. The case where $x < k$ is straightforward. Recall that, by Assumption 2, the project has positive NPV as long as k consecutive good signals are generated. This implies that independently of her information, an agent would never have an incentive to back a project whose implementation relies on a history where fewer than k agents back the project, as this would imply financing a negative NPV project. Anticipating that, the agent does not have an incentive to gather information in the first place.

We now explore the case where $x > k$. Consider the problem of an agent who moves in period $k+1$, conditional that all k preceding agents chose to back the project. Assumption 2 combined with Lemma 1 and Lemma 2 imply that for the agent who moves in period $k+1$, the option of backing the project without acquiring information has positive expected utility. As a result, if the entrepreneur wishes to incentivize agent $k+1$ to gather information, she should leave enough surplus to this agent such as the expected utility of acquiring information exceeds the positive expected utility of backing the project without acquiring information. Consequently, all agents would have strong preference to move later than earlier, as moving later allows an agent to free-ride on the information produced by the preceding agents. Therefore, for the agents to be indifferent, the entrepreneur should offer a contract which leaves the same expected surplus independently of the time each agent is called to take her backing decision, i.e., (5) holds. As a result, if the entrepreneur wishes to implement $x = k+1$, that would mean that she would have to give away a significant part of the surplus due to the fact that agents can always free-ride on their peers' information, which generates positive expected utility.

Summing up, incentivizing the first k instead of $k+1$ agents to back the project only if they are positively informed effectively eliminates free-riding incentives. This, in turn, allows the entrepreneur to finance her project by giving away less equity.

On top of the channel highlighted in the previous paragraph, implementing $x = k$ instead of $x = k+1$, implies a higher probability of financing the project. Recall that, all else equal, the entrepreneur would like to minimize the probability of not financing the project, because this leads to zero profit. As a result, $x = k$ dominates any $x > k$ via two channels: implementing $x = k$ instead of $x = k+1$ not only increases the probability of financing, but also increases the equity the entrepreneur retains in case of financing. Besides, as we showed earlier, $x = k$ also dominates any $x < k$. Thus, the optimal value is $x = k$. □

4.1.1 Revising the Maximization Problem

Following the previous claims, we can eliminate a series of constraints in the initial maximization problem. In particular, Lemma 1 implies that for each $t = \{0, ..., k\}$:

$$\mathbb{E}\, U_t(back|\sigma = \sigma_B, \Omega_t) < 0$$

$$\mathbb{E}\, U_t(no\ signal\ \&\ back|\Omega_t) < 0$$

These two relations hold because, by Lemma 1, the project has negative NPV, even in the extreme case where $k-1$ agents have observed a good signal. Also, recall that the potential investors' outside option is normalized to zero, thus,

$$\mathbb{E}\, U_t(no\ back|\sigma_G, \Omega_t) = 0.$$

In addition, given that acquiring a positive signal is the best case scenario when it comes to the decision of acquiring information and given that the RHS of (1) is zero, (1) is redundant by (4). Finally, under the optimal contract, the participation constraint of each agent (4) binds, therefore, the expected utility of each agent is zero. A consequence of the latter is that constraint (5) becomes redundant. Based on the previous analysis, the maximization problem simplifies to:

$$\underset{C(\bar{\mathcal{FR}}(\mathcal{H}),\ \alpha(\mathcal{H}'),\ \mathcal{I}(\mathcal{H}'))}{\text{Maximize}} \quad \mathbb{E}[Pr(H_J)\bar{\mathcal{FR}}(\mathcal{H})(H_J)Pr(\theta = H|H_J)(1-\alpha(H_J))|\Omega^{ent}]$$

s.t. for each $t = \{0, ..., k\}$:

$$\mathbb{E}\, U_t(signal|\Omega_t)) \geq 0 \tag{7}$$

$$\text{For each } H_J \in \mathcal{H}',\ I_1 + ... + I_k = I \tag{8}$$

4.2 Step 2: Optimal Financing Rule

Lemma 4: *Under the optimal contract, the project is financed as long as the first k investors back the project. Otherwise, the capital raising process is terminated with the entrepreneur not raising any funds. Thus, the optimal contract exhibits an All-or-Nothing (AON) feature.*

We start by providing the underlying intuition for the case where $k = 2$. The same rationale extends to the case where $k > 2$.

Suppose that the first agent acquires information and observes a good signal. Recall that by Assumption 2, observing just one good signal is not sufficient for the project to have positive NPV. Therefore, the first agent would never find it optimal to finance the entire project, even in the extreme case where she receives the entire surplus. i.e., $\alpha = 1$.

Consider now a contract which does not exhibit an AON feature and the project is financed *independently* of the backing decision of the second agent.[16] That regime would imply that the first agent: i) finances the entire project when the second agent observes a bad signal (thus, when the project has negative NPV); and ii) finances part of the project when the second agent

[16]This would be equivalent to a *Take-it-All* feature, usually encountered in donation-based CFPs.

observes a good signal (thus, when the project has positive NPV). In other words, without an AON feature, the first agent would have to finance the entire project in the bad state of the world, and finance part of the project in the good state of the world. It is evident that the expected return associated to this contract is lower than the expected return when financing the entire project. However, as explained in the previous paragraph, by Assumption 2, the first agent would never find it optimal to finance the entire project even if she observes a good signal. Thus, the same holds true for any contract that lacks an AON feature. Note also that as the first agent finds it suboptimal to invest independently of her signal realization, she will not have an incentive to acquire information in the first place.[17]

The rationale provided for the case where $k = 2$ can be extended to the case where $k > 2$. Staring from analyzing the incentives of the agent who moves in period $k - 1$, it can be shown that it is never optimal to invest nor to gather information. Following that, the same argument unravels to all preceding agents.

4.3 Optimal Contract

Combining Lemmas 2, 3 and 4, the maximization problem simplifies to:

$$\underset{\alpha,\ I_1 \ldots I_k}{\text{Maximize}} \quad \mathbb{E}[Pr(\sigma_1 = \sigma_G \cap \sigma_1 = \sigma_G \cap \ldots \cap \sigma_k = \sigma_G)|p_0][p_k(1-\alpha)]$$

s.t. for each $t = \{0, \ldots, k\}$:

$$\mathbb{E}\, U_t(signal|\Omega_t) \geq 0 \tag{9}$$

$$\text{For each } H_J \in \mathcal{H}',\ I_1 + \ldots + I_k = I \tag{10}$$

where,

$$\mathbb{E}[Pr(\sigma_1 = \sigma_G \cap \sigma_1 = \sigma_G \cap \ldots \cap \sigma_k = \sigma_G)|p_0][p_k(1-\alpha)] = [p_0 s_G^k + (1-p_0)s_B^k](1-\alpha)$$

and,

$$\mathbb{E}\, U_t(signal|\Omega_t) = \mathbb{E}[Pr(\sigma_t = \sigma_G \cap \sigma_{t+1} = \sigma_G \cap \ldots \cap \sigma_k = \sigma_G|p_t][p_k \alpha \frac{I_t}{I} - I_t] - c \geq 0 \tag{11}$$

[17] We provide the algebraic proof in the Appendix.

which simplifies further to:

$$\mathbb{E}\, U_t(signal|\Omega_t) = [p_t s_G^{k-t} + (1-p_t) s_B^{k-t}][p_k \alpha \frac{I_t}{I} - I_t] - c \geq 0 \tag{12}$$

where p_t indicates the beliefs of the agent who moves in period t, given that all preceding agents back the project.[18] Thus, solving the maximization problem coincides with deriving: i) the minimum value of equity the entrepreneur needs to offer; and ii) the corresponding amount that each agent $i \in \{1, ..., k\}$ should invest, such as the participation constraint of each agent i binds. The optimal contract is given in Proposition 1.

Proposition 1: *Under the optimal contract, potential investors take their backing decisions sequentially, and the project is financed as long as the first k agents back the project. Otherwise, the capital raising process is terminated with the entrepreneur not raising any funds (i.e., the contract exhibits an AON feature). Conditional on the project being financed, the investment of the agent who moves in period $t \in \{0, k\}$ is given by:*

$$I_t^* = I \frac{p_0 s_G^t + (1-p_0) s_B^t}{\Sigma_{j=1}^k [p_0 s_G^{j-1} + (1-p_0) s_B^{j-1}]}$$

Also, the equity level allocated to investors is given by:

$$\alpha^* = \frac{I[p_0 s_G^k + (1-p_0) s_B^k] + c \Sigma_{j=1}^k [p_0 s_G^{j-1} + (1-p_0) s_B^{j-1}]}{p_0 s_G^k}$$

Proposition 1 states that offering a contract for which the backing decisions are taken sequentially is optimal. We discuss this finding in the next section. Corollary 1 sheds light on the dynamics and shows how the individual investment changes over time.

Corollary 1: *Under the optimal contract, the individual investment decreases over time, i.e., $I_t > I_{t+1}$.*

Corollary 1 implies that early backers finance a higher share of the project. The intuition is straightforward. The earlier an agent moves, the lower the probability that she attributes to the

[18] Recall that for this contract, an agent backs the project only when holding positive information.

event that k consecutive good signals will be produced, such as the project is finally financed. Thus, agents who move earlier have to be compensated by being promised higher expected revenue if the project is finally financed. This is achieved by allowing agents who move early to finance a larger part of the -conditional on being financed- positive NPV project.[19]

4.4 Simultaneous backing decisions

In order to show that the entrepreneur prefers the backing decisions to be taken sequentially, we first characterize in Proposition 2 the optimal contract, when, by assumption, the backing decisions are taken simultaneously, and subsequently compare the entrepreneur's expected utility in these two regimes.

Proposition 2: *Assuming that potential investors take their backing decision simultaneously, under the optimal contract, the entrepreneur approaches k agents and the project is financed as long as all of them back the project. Otherwise, the capital raising process is terminated with the entrepreneur not raising any funds. Conditional on the project being financed, each agent contributes the same amount $I_i = I/k$ and the equity level allocated to investors is given by:*

$$\tilde{\alpha}^* = \frac{ck + I[p_0 s_G^k + (1-p_0)s_B^k]}{p_0[p_0 s_G^k + (1-p_0)s_B^k]}$$

Proof. See Appendix. □

Evidently, for economic parameters for which $\tilde{\alpha}^* > 1$, the market collapses and the entrepreneur fails to raise capital with probability one. Besides, it is worth highlighting that for $\alpha^* \leq 1$ and $\tilde{\alpha}^* \leq 1$, the probability of financing is the same independently of whether investors move sequentially or simultaneously. This relies on the combination of the AON feature with the finding that the optimal target is the same in both regimes. Also, simple algebra shows that $\alpha^* < \tilde{\alpha}$, which leads to the following Corollaries.

[19] Alternative, we could restrict the agents to have the same investment, but allowing early investors to receive higher equity.

Corollary 2: *Allowing potential investors to take their backing decisions sequentially alleviates under-financing of projects that would not be financed if potential investors took their backing decision simultaneously.*

Corollary 3: *The entrepreneur always prefers the backing decisions to be taken sequentially.*

The underlying intuition in Corollary 2 and 3 is two-fold. First, when the backing decisions are taken sequentially, the entrepreneur can use the information produced by early investors, to motivate late investors. As a result, allowing investors to learn from each other allows the entrepreneur to motivate information production at a lower cost, i.e., lower equity distributed to the investors. Second, note that restricting agents to move simultaneously might give rise to over-production of information; if a bad signal is observed, then uncertainty is resolved, thus, any further information acquisition is socially wasteful.[20] Therefore, acquiring information sequentially leads to a better allocation of resources.

5 Link with security-based crowdfunding

An important assumption that we adopt throughout the paper regards to the ability of the entrepreneur and potential investors to commit. More specifically, we assume that the entrepreneur can commit to implementing the project only if a sufficient number of agents back it. Besides, we assume that potential investors can commit to investing if the predetermined number of backers is reached. These assumptions are critical for our main findings. In what follows, we explain that relaxing these assumptions might lead to a coordination failure in information production, which prevents the implementation of the project. Next, we elaborate on the economic environments in which we would expect agents to have the ability to commit. Finally, we provide a rationale for the emergence of CFPs and explore the implications of our study for the design of the capital raising process in crowdfunding platforms.

[20] A similar rationale would apply even if the uncertainty is never resolved, i.e. $s_G < 1$. This is true because if many good or many bad signals are observed, then the benefit of acquiring one more signal would not exceed its cost, c.

Relaxing Commitment Assumption

Note that in a setting of costly information acquisition and information complementarities, potential investors have an incentive to follow a "wait and see" strategy, which consists of two steps. First, to back the project in order to motivate the peers to gather information. Second, to acquire information only if everyone else backs the project, and subsequently withdraw the backing decision if a bad signal is observed. These free-riding motives imply that each agent has an incentive to deviate unilaterally, which could lead to a coordination failure and information production breakdown. As a result, lack of commitment can prevent the financing of socially valuable projects, that would be financed otherwise.

One possible way the entrepreneur could deal with an investor's lack of commitment would be the latter to transfer to the former the maximum contribution which is consistent with the equilibrium path, which will be partly or fully refunded after the backing decisions are taken. This would be sufficient as long as the entrepreneur cannot run or implement the project even when it is not supposed to be implemented. Alternatively, the entrepreneur could include a set of clauses that punish the agent for withdrawing a backing decision. These cases imply a sort of completeness in contracts, which is not always a realistic assumption.

We now explore the case where the entrepreneur cannot commit to implementing the project only if certain conditions are satisfied. One could come up with examples where the entrepreneur might want to deviate from that. For instance, suppose the case where the project requires five consecutive good signals to become creditworthy. Suppose now that the first four agents have backed the project, which implies that the updated beliefs that the demand is high are higher compared to the time of contracting. Following that, the entrepreneur might have an incentive to cancel the capital raising project and offer a new contract to a different crowd with more favorable for her terms.

Another example where the entrepreneur might have an incentive to deviate is when the first four agents have backed the project, whereas the fifth one observes a bad signal and decides not to back the project. If this is the case, the entrepreneur could collude with the fifth agent such as the latter, in exchange for a transfer, backs the project which leads to its financing.[21]

Commitment power and reputation concerns

One critical factor which determines commitment power is reputation concerns. Although this is something that is not modeled in the present paper, it seems reasonable to expect that reputation concerns are stronger for agents who are going to be raising capital multiple times. Based on the previous rationale, one would expect professional investors, such as venture capitalists, and firms that might wish to raise external capital multiple times in the future, to be less tempted to deviate.

Economic Value of Crowdfunding Platforms

Section 4 highlights that if economic agents can commit, then information can be aggregated and communicated efficiently. However, this finding might not go through in regimes which are characterized by lack of commitment. Therefore, introducing a third party that allows economic agents to commit would lead to a better allocation of resources, that would be beneficial for all parties involved. The role of a third party can be played by a CFP.

Therefore, a CFP can provide an environment such that: i) the project is financed only if the predetermined number of backers is reached, and; ii) potential investors cannot withdraw their backing decisions. In a CFP, the former is achieved by implementing an AON feature, and the latter by making investors' backing decisions binding.[22]

Thus, the present paper suggests that CFPs can create economic value not due to project screening, but due to overcoming individuals' lack of commitment. By overcoming lack of commitment, CFPs can create an environment that the market itself determines whether a project is creditworthy, which might eventually lead to the financing of positive NPV projects that would not be financed otherwise. This channel is consistent with Mollick and Nanda (2015) who provide evidence that crowdfunding can play an important role by allowing projects the

[21] Recall that the entrepreneur is protected by limited liability, thus, she would prefer to implement the project, even when she believes that it has negative NPV.

[22] Recall that the entrepreneur's only action is to design the optimal contract. Thus, the implementation of the contract can be easily delegated to a platform, as there is no additional action taken by the entrepreneur.

option to receive multiple evaluations and thereby lowering the incidence of "false negative", i.e., not financing a creditworthy project. Besides, this channel is consistent with the idea that the fundamental role of CFPs is not to evaluate investment projects, but to provide an environment which can implement the wisdom of the crowd. The wisdom if the crowd is supported by Lee, Li, and Shin (2018) in an Initial Coin Offering (ICO) setting, which, however, has similar features with crowdfunding.

Summing up, our work suggests that CFPs might be useful for investors and entrepreneurs who have limited commitment power. This is consistent with the types of economic agents that we observe in CFPs, namely small, not very experienced investors and young, not very experienced entrepreneurs.[23]

Design of Crowdfunding Platforms

The main findings of the paper, and in particular the optimal contract, produces clear implications about the optimal design of the capital raising process in CFPs. Note that in the setting we study, the allocation of resources which maximizes welfare coincides with the allocation of resources which maximizes the entrepreneur's expected profits.[24] Therefore, as long as the objective of a CFP is to maximize the entrepreneur's profit or to achieve the best allocation of resources, our work generates the following set of implications.

Corollary 4: *Implications for the design of Crowdfunding Platforms.*

(i) *Backing decisions shall be taken sequentially and shall be observable.*

(ii) *Financing shall go through as long as enough investors back the project. Otherwise, the campaign shall be canceled.*

(iii) *Investors who back the project earlier shall get better terms.*

[23]The report *The Future of Finance - The Socialization of Finance* (2015) by Goldman Sachs provides an a review of the crowdfunding industry, capturing the type of projects that have raised capital via CFPs and the type of investors involved in crowdfunding.

[24]This is a consequence of risk neutrality and of the assumption of perfectly competitive markets which implies that, under the optimal contract, investors break-even.

Link with Crowdfunding Platforms

Although our setting adopts a number of simplifying assumptions, the main predictions are consistent with what is common practice in CFPs. For instance, all security-based crowdfunding platforms are characterized by an All-or-Nothing feature, where the target is determined at the time the capital raising process is initiated. Besides, at any point, either the number of investors that have backed the project and/or the total contribution is observable to all agents.

Something that is less obvious is whether CFPs allow for a premium for moving earlier than later. Our paper focuses on the case where the amount that an agent can invest is decreasing in the number of agents that have already backed the project. However, there are different ways of implementing this feature. For example, as mentioned earlier, another way of rewarding early movers is by allowing the equity per unit invested to be decreasing over time. A similar feature exists in ICOs. It is common in ICOs for early backers to receive a discount, which effectively decreases the cost per token. Besides, given that in most CFPs part of their commission is a transaction fee paid by the investors, the reward for early investors could be implemented by setting a transaction fee which is decreasing over time.

Regarding the selection of projects and participants in CFPs, our model's predictions are summarized in Corollary 5.

Corollary 5: *Implications for type of projects and economic participants.*
Crowdfunding would be particularly attractive to:

(i) *agents who lack commitment power, such as new startups and amateur investors.*

(ii) *projects that are characterized by a high degree of demand uncertainty, such as innovative projects.*

The first part relates to the idea that startups and amateur investors, due to their inability to commit, might fail to aggregate information. A CFP can help economic participants to overcome the lack of commitment, which prevents the financing of socially valuable projects.

The rationale behind part two can be captured by the following example. Suppose that an entrepreneur has two options: either to raise capital from a venture capitalist (VC) or to raise capital via a CFP. One could argue that raising capital via a VC might improve the probability of success of the project, due to the support that an experienced investor can provide. However, by raising capital via a CFP, an entrepreneur can utilize the positive information produced by the market to get better financing terms. Therefore, on the one hand, raising capital from a VC can increase the size of the pie, but on the other hand, raising capital via a CFP allows the entrepreneur to retain a larger slice of an arguably smaller pie. If this is the case, the optimal method would depend on which force dominates. Part two of Corollary 5 relates to the observation that, all else equal, information asymmetry is more severe for innovative projects, thus, the benefit of using a platform to gather information is stronger.

6 Concluding Remarks

The present paper builds on two observations. First, innovative products are characterized by demand uncertainty. Second, economic participants might have access to relevant information about the product's future demand, but the information each individual has is costly and limited. Following these two observations, we show that there is room for learning from the market, which has consequences for the capital raising process and the allocation of resources. In this setting, where information complementarities arise, we characterize the optimal contract for raising capital. We show that the optimal contract that incentivizes information production and information communication has three features: i) the backing decisions are taken sequentially and are observable; ii) the project is financed if a sufficient number of investors back the project, otherwise the capital raising process is terminated, and; iii) early backers get better terms.

This paper contributes to the general understanding behind the economic value of security-based crowdfunding, and the design of the capital raising process in these platforms. Regarding the former, we highlight that CFPs could help economic participants overcome the lack of commitment which prevents information production and alleviates the problem of under-financing. Regarding the latter, we shed light on the conditions under which a CFP can create an environment that implements the wisdom of the crowd.

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Appendix A:

A.1 Relaxation of $s_G = 1$

In this Section, we explore how the main findings would change if we relax the assumption that $s_G = 1$. Recall that this assumption implies that a bad signal reveals that the demand is low with certainty, which, in turn, implies that the project has negative NPV.

Lemma A.1: *For $s_G < 1$, if the cost of gathering information is sufficiently small (i.e.,* (13) *is satisfied), it is always optimal for the entrepreneur to stop incentivizing information acquisition and terminate the ongoing capital raising process when an action is consistent with a bad signal.*

Consider the case where the project requires five consecutive good signals to have positive NPV (prior belief is p_0). Suppose now a history which is consistent with four good signals followed by one bad signal. Suppose also that this history leads to updated beliefs, denoted as $\bar{p}$ that exceed the ex-ante beliefs p_0. As the entrepreneur has limited liability, she would like to continue the experimentation. Given that, she has two options. One option is to terminate the ongoing capital raising process, and start a new capital raising process by offering a new contract to a new pool of investors. Doing so would allow her to raise capital at a lower cost because the beliefs at the time of contracting are better than before (given that $\bar{p} > p_0$). However, the existing backers would prefer the entrepreneur not to terminate the capital raising process because they have already incurred the sunk cost of acquiring information. Therefore, by terminating, the entrepreneur makes the existing backers worse-off compared to the case with no termination, thus she must give away more equity. In other words, it would be ex-post optimal for the entrepreneur to seek capital from a new pool of investors, but this affects negatively the equity given away in the initial capital raising round. Therefore, there are two conflicting forces when the entrepreneur decides whether to seek capital from a new pool of investors.

Here we explain the intuition why the first force dominates, which implies that it is optimal to, first, terminate the capital raising process when an agent decides not to back the project, and second, raise capital from a new pool of investors. The underlying mechanism relates to the marginal benefit of gathering information after a bad signal is observed. Note that if the capital raising process is not terminated, part of the investment has to be financed by early backers. This decreases the remaining stake which is distributed to the new backers, which makes it more difficult to incentivize an additional agent to gather information. In other words, raising capital from a new pool of investors is a more efficient way to incentivize information acquisition because the marginal benefit of gathering information is increasing in the amount that an agent is supposed to invest. For instance, think of the extreme case where 90% of I is covered by the existing backers. This implies that even if the project has positive NPV, the amount than an agent can invest is very small, thus, the incentive to gather information is very weak. Thus, the entrepreneur can only incentivize the agent to gather information by giving away a significant amount of equity.

It is critical to understand that the previous argument goes through as long as the entrepreneur can raise capital even if the capital raising process is terminated after a bad signal. This is true, as long as $\alpha^* \leq 1$, which holds if c is sufficiently small. Recall that the optimal value of equity is:

$$\alpha^* = \frac{I[p_0 s_G^k + (1-p_0)s_B^k] + c\Sigma_{j=1}^k [p_0 s_G^{j-1} + (1-p_0)s_B^{j-1}]}{p_0 s_G^k}$$

We can re-write the previous condition as follows:

$$\alpha^* = \underbrace{\frac{I}{p_k}}_{<1} + c \underbrace{\frac{\Sigma_{j=1}^k [p_0 s_G^{j-1} + (1-p_0)s_B^{j-1}]}{p_0 s_G^k}}_{>0}$$

Note that $p_k > I$ given that the project has positive NPV at the time of implementation. Therefore, $\alpha^* \leq 1$ as long as c is sufficiently small, i.e.,

$$c \leq \hat{c} \equiv \frac{(s_B - 1)(s_G - 1)\left(I(p_0 - 1)s_B^k - I p_0 s_G^k + p_0 s_G^k\right)}{p_0\left(-(s_G - 1)s_B^k + s_B\left(s_G^k - 1\right) - s_G^k + s_G\right) + (s_G - 1)\left(s_B^k - 1\right)} \tag{13}$$

The previous analysis implies that focusing on the $s_G = 1$ case is without loss as long as (13) is satisfied. However, if (13) is violated, the entrepreneur has to promise a positive payoff for the histories for which one of the potential investors decides not to back the project, otherwise agents are not compensated enough to gather costly information. This case increases significantly the complexity of the analysis, without affecting the main features of the contract. Note that there might be a large number of histories for which the project has positive NPV, which implies that there is a large number of histories for which the project is financed. Also, for each of the histories that the project is financed, the entrepreneur has to offer an investment scheme and the corresponding equity level distributed to investors. Therefore, the extent of the contract increases tremendously. However, for each history that the project is financed, the incentives of the agents involved in the capital raising process remain the same as in Section 4. Therefore, the main features of the contract are unchanged: i) the backing decision are taken sequentially and are observable; ii) for each history, there is a unique target in the number of backers that the project needs to reach for the project to be financed.

A.2 Incentivizing information acquisition by analysts

Throughout the paper, we implicitly assume that the entrepreneur relies on potential investors to gather information. A question that arises naturally is whether the entrepreneur could delegate the information acquisition process to financial experts. Lemma A.2 implies that assuming that the entrepreneur can only gather information via potential investors is without loss as long as the entrepreneur and financial analysts have limited liability.

Lemma A.2. *When the entrepreneur and an analyst have limited liability, it is not feasible to gather information from the latter, unless she is compensated via equity.*

Proof. Recall that, by Assumption 1, neither the signal acquisition nor the signal realization is verifiable, therefore, the entrepreneur needs to incentivize the analyst. Similar to the benchmark model, in order to motivate information acquisition, the entrepreneur should offer a contract that satisfies two sets of constraints. First, the analyst should have an incentive to gather information. Also, conditional that information has been acquired, the analyst should have an incentive to reveal it truthfully.

Suppose that conditional on acquiring information, the analyst observes a good ($\sigma = \sigma_G$) or bad ($\sigma = \sigma_G$) signal, such as $Pr(\theta = H|\sigma = \sigma_G) > Pr(\theta = H|\sigma = \sigma_B)$. Suppose also contracts which are contingent on the observables, namely the recommendation of the analyst, $\tilde{\sigma} = \{\tilde{\sigma}_G, \tilde{\sigma}_B\}$ and the realized demand, θ. Note that the demand is realized only if the project is implemented, and the project is implemented only after a good recommendation, conditional that the analysts reveals her signal truthfully. Therefore, the contract the entrepreneur offers to the analyst consists of three parts, $W = \{w_H, w_L, w\}$, where w_H (w_L) stands for the payment when the analyst issues a good recommendation, the project is implemented and the demand turns out to be high (low). Also, w stands for the payment when the analyst issues a bad recommendation, which as we explained earlier, cannot be contingent on future demand, as the demand is never realized.

Note also that the entrepreneur finds it optimal to incentivize information acquisition only if the recommendation is pivotal, i.e., the project has positive NPV if the signal is good and negative NPV otherwise. Following these remarks, an informed analyst has an incentive to reveal her private signal truthfully as long as:

$$EU(\tilde{\sigma} = \tilde{\sigma}_G|\sigma = \sigma_G) \geq EU(\tilde{\sigma} = \tilde{\sigma}_B|\sigma = \sigma_G) \implies Pr(\theta = H|\sigma = \sigma_G)w_S + Pr(\theta = L|\sigma = \sigma_G)w_F \geq w$$

$$EU(\tilde{\sigma} = \tilde{\sigma}_B|\sigma = \sigma_B) \geq EU(\tilde{\sigma} = \tilde{\sigma}_G|\sigma = \sigma_B) \implies w \geq Pr(\theta = H|\sigma = \sigma_B)w_S + Pr(\theta = L|\sigma = \sigma_B)w_F$$

Combining these two constraints, pins down to:

$$Pr(\theta = H|\sigma = \sigma_G)w_S + Pr(\theta = L|\sigma = \sigma_G)w_F \geq w \geq Pr(\theta = H|\sigma = \sigma_B)w_S + Pr(\theta = L|\sigma = \sigma_B)w_F \tag{14}$$

Note that due to the entrepreneur's limited liability, $w \geq 0$. Therefore, the only way for (14) to hold is if $w_F < 0$, which contradicts with the analyst's limited liability. Thus, there is no contract which induces the analyst to reveal her private signal truthfully. As a result, if the entrepreneur and the analyst have limited liability, the former cannot gather information from the latter, unless the latter is compensated via equity. □

A.3 Proof of Proposition 2

An important feature of the optimal contract provided in Proposition 2 is the target that the project needs to reach for financing to go through. This target, although it has a slightly different interpretation, arises in this setting as well. In Proposition 1, the target refers to the number of positively informed backers that is required for the project to be financed. In contrast, in a setting where agents move simultaneously, the target regards the number of potential investors that the entrepreneur approaches, i.e., offers a contract to.

Lemma A.3: *Under the optimal contact, the number of potential investors that the entrepreneur approaches is k.*

The intuition is similar to the underlying intuition in Lemma 3.

Lemma A.4: *Under the optimal contact, the project is financed only if all k potential investors decide to back the project.*

The intuition behind the AON feature is similar to the intuition in Lemma 4, which can be captured below. Consider the problem of each agent when the contract does not have an AON feature. Suppose that each agent believes that all potential investors who were approached by the entrepreneur find it optimal to gather information and invest only if they receive a good signal. Finally, consider an agent who holds a good signal. This agent expects that with probability $1-p_1$ she will end up financing a negative NPV project. However, by Assumption 2, the agent does not have an incentive to invest in the project even if her equity is one. Following that, the agent does not have incentive to acquire information in the first place. Summing up, lack of an AON feature implies that even if an agent is positively informed and she expects everyone else to gather information and invest when being positively informed, then she would never have an incentive to invest, let alone gather information.

Finally, as the game is symmetric, $I_i = \frac{I}{k}$ for each $i \in \{1, .., k\}$. Combining the previous two observations, the maximization problem pins down to:

$$\underset{\alpha}{\text{Maximize}} \quad \mathbb{E}[Pr(\sigma_1 = \sigma_G \cap \sigma_1 = \sigma_G \cap ... \cap \sigma_k = \sigma_G)|p_0][p_k(1-\alpha)]$$

$$\mathbb{E}\, U_i(signal|\Omega_i)) \geq 0 \tag{15}$$

where

$$\mathbb{E}[Pr(\sigma_1 = \sigma_G \cap \sigma_1 = \sigma_G \cap ... \cap \sigma_k = \sigma_G)|p_0][p_k(1-\alpha)] = [p_0 s_G^k + (1-p_0)s_B^k](1-\alpha)$$

$$\mathbb{E}\, U_i(signal) = Pr(\sigma_1 = \sigma_G \cap \sigma_2 = \sigma_G \cap ... \cap \sigma_k = \sigma_G|p_0)[p_k a\frac{1}{k} - \frac{I}{k}] - c \geq 0 \tag{16}$$

which simplifies further to:

$$\mathbb{E}\, U_t(signal) = [p_0 s_G^k + (1-p_0)s_B^k][p_k a\frac{1}{k} - \frac{I}{k}] - c \geq 0 \tag{17}$$

The solution of the maximization problem is summarized in Proposition 2.

A.4 Proof Lemma 4

More formally, for $k = 2$ and for a contract without an AON feature, it can be shown that the equity level which solves the maximization problem is given by:

$$\alpha' = \frac{I[ps_G + (1-p)s_B] + c[1 + ps_G + (1-p)s_B]}{ps_G}$$

Note that for $\alpha' \leq 1$ it must be that:

$$I \leq \frac{ps_G}{ps_G + (1-p)s_B} - c\frac{1 + ps_G + (1-p)s_B}{ps_G + (1-p)s_B} \tag{18}$$

However, by Assumption 2:

$$I \geq \frac{ps_G}{ps_G + (1-p)s_B}$$

Thus, (18) cannot be true, therefore α' is not feasible.