Learning through Crowdfunding*

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Abstract

We develop a model where reward-based crowdfunding enables firms to obtain a reliable proof of concept early in their production cycle. The information gathered from a subsample of backers through a fixed length pre-selling campaign enables firms to update their beliefs about the preferences of all future consumers. This creates a valuable real option as firms invest only if updated demand is high. Further, such updating mitigates moral hazard: the higher the funds raised, the lower the firms' incentives to divert them. Our results are consistent with stylized facts and provide new testable implications.

JEL codes: D80, G30, L14, L26, O30

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1 Introduction

Reward-based crowdfunding platforms enable firms to raise funds directly from future consumers, at an early stage of product development, and before making substantial investments. Funds are typically exchanged for a promise of the future delivery of a new product.¹ The funds raised through reward-based crowdfunding have been substantial and are expected to grow rapidly. Massolution (2016) estimates that \$5.5 billion were raised through reward-based crowdfunding globally in 2015, i.e., over 10% of new venture capital investments, while Statista (2017) forecasts that \$19 billion will be raised in 2021 in the 50 countries covered in their digital market outlook.²

The projects that raise the most substantial amounts develop innovative consumer products. Indeed, as of January 31, 2017, 61% of the \$2.5 billion raised through the Kickstarter platform have been collected by firms that produce technology, design or gaming products.³ While successfully funded projects, i.e., projects that met their funding target, raised \$21K on average across all categories, an average successfully funded project in technology, design and games raised \$90K, \$62K and \$55K, respectively. Further, many of these projects have raised funds comparable to those raised during an angel or venture capital investment round.⁴ This success may seem surprising in the light of a well-known moral hazard problem (Tirole, 2006): firms may be tempted to divert funds they raised instead of delivering the products. Perhaps even more surprising is the observation that innovative firms are those that appear to benefit the most from reward-based crowdfunding. After all, these firms are particularly prone to moral hazard and informational frictions

¹See e.g., Mollick 2014. The defining characteristics of reward-based crowdfunding is that contrary to equity-based crowdfunding and peer-to-peer lending, firms are not allowed to offer any financial rewards (see e.g., rules at Kickstarter <https://www.kickstarter.com/rules>).

²See <https://www.statista.com/outlook/335/100/crowdfunding/worldwide#market-transactionValue>

³The data available in the "Stats" section of www.kickstarter.com indicate that from Kickstarter's launch on April 28, 2009 to January 31, 2017, around 120,000 projects out of 340,000 launched in 15 categories were successfully crowdfunded. We have also collected more detailed data on a subsample of all projects launched in the Technology and Theatre categories from January 1 to September 17, 2015.

⁴Business angel and venture capital have traditionally been considered to be the best sources of financing risky and innovative projects (Bussgang 2014, Lerner et. al. 2012). Venture capitalists (business angels) usually make investments worth over (below) \$1 million. One of the most successful firms on Kickstarter, Pebble Technology Corporation, raised over \$10 million in 2012, then \$20 million in 2015, and then again \$12 million in 2016 in exchange of the promised delivery of their Pebble Smartwatch. As of January 31, 2017, about 240 projects have raised over \$1 million and about 4,000 projects have raised over \$100 000 on Kickstarter alone.

(Bussgang 2014).

In this paper we develop a model of crowdfunding that provides a rationale for these and other stylized facts. We emphasize that in addition to providing funding, reward-based crowdfunding platforms play an important role in enabling firms to learn about demand before making their investment decisions. Pre-selling through these platforms can be viewed as a credible consumer survey. Since consumers pay noticeable amounts, they do not have incentives to overstate their valuation for products. For example, in 2015, the average backer contribution in a technology project was \$200 while the median was \$100. This consumer survey feature is made possible by a short, fixed length campaign, e.g., 1 to 60 days on Kickstarter, that ensures that only a subsample of potential consumers can find the product during the campaign. Observing the decisions of a random subsample of consumers enables the firm to update its beliefs about preferences of *all* their future consumers, which creates a substantial real option value and enables the firm to endogenously overcome moral hazard.

Our model emphasizes the real option of learning, which comes from the firm's ability to develop a project only after it observes sufficiently high consumer demand, and to save on the investment cost if demand is low. We show that the value of learning increases with the level of prior uncertainty about future demand. This may explain why firms that develop consumer products that involve a high degree of demand uncertainty, such as technology gadgets and computer games, have most to gain from crowdfunding. High prior uncertainty implies that crowdfunding campaigns are likely to both fail and raise funds multiple times over the target with a high probability (see Section 6). We further show that the option value of learning is maximized when investment costs are intermediate, i.e., when projects have a NPV close to zero based on prior beliefs, and that the overall relationship between the value of learning and investment costs is inverted U-shaped. Such learning is valuable whether or not the firm is financially constrained.

Our model incorporates moral hazard, as reward-based crowdfunding platforms are not legally responsible for guaranteeing the delivery of rewards and proving that a firm has committed a fraud is difficult.⁵ Nevertheless, the vast majority of projects do deliver rewards (Mollick 2014). We argue that the rarity of diversion is not due to limited moral hazard, but is due to the consumer survey feature of

⁵Conor, Gaffey, 2015, "\$122,000 Kickstarter Fraud Case Highlights Dangerous Lack of Regulation, *Newsweek*, 12 June

crowdfunding, which gives firms sufficient incentives to deliver rewards. We show that campaigns that raise more funds have higher incentives to deliver products. Specifically, an increase in the number of consumers who pre-order the product during the campaign has two conflicting effects: On the one hand, an increase in the funds available increases the funds available to be diverted. On the other hand, an increase in pre-orders leads firms to update their expectations upwards. The increase in expected future sales dominates the immediate benefits of diverting funds.

For such Bayesian updating to occur, the firm must be uncertain about the distribution from which consumer preferences are drawn. To this end, we assume that each consumer’s valuation for the product is either 0 or 1, where the probability at which each consumer draws a high valuation is initially unknown to the firm. Consumers pre-order the product based on their own valuation, enabling the firm to update its beliefs about the distribution of valuations and total demand. More generally, it is required that the sample from which the firm learns about demand does not consist of individuals whose valuations are uncorrelated with that of other potential consumers. If this were the case, we would expect a small group of them to repeatedly pre-order products. However, this is at odds with the observation that the vast majority, 68% of 12.3 million backers, have only contributed to one project on Kickstarter. Since thousands of campaigns are live every day and remain live only for a short period of time, it is sensible to consider the Kickstarter sample of consumers to be representative.

We argue that third-party crowdfunding platforms bring value by externalizing commitment, enabling firms to commit to transparency and to a fixed and limited campaign length.⁶ Transparency ensures that backers observe each other’s pledges during the campaign and can coordinate not to back a firm that they expect will have insufficient incentives to invest. Beside alleviating moral hazard, transparency benefits the firm, which can then pre-sell the product at a minimal discount. A fixed, limited campaign length ensures that a firm can only pre-sell the product to a limited subset of backers. In equilibrium, all consumers who find the product during the campaign and value it pre-order it, and the firm sets the target so that backers do not need to actively coordinate.⁷

⁶Dewatripont (1988) examines the constraints that renegotiation imposes on firms’ ability to commit to contracts with third parties. Third-party platforms would find it difficult to renegotiate previous contracts as their reputation would suffer from this.

⁷In practice, backers may coordinate when pledges are public and backers can back the project and then withdraw any time during the campaign.

We further compare the All-or-Nothing (AoN) and Keep-it-All (KiA) schemes.⁸ We show that AoN outcomes are (almost) first best schemes, i.e., equivalent to a frictionless consumer survey, even in the absence of a reputation cost and legal risk. While the firm must set a target that is higher than the first best investment threshold, learning about demand is also valuable to a firm that does not meet the target. Since the equilibrium target is higher than the optimal investment threshold, this firm may still choose to invest and to complete the project, and the absence of funds to divert ensures that there are no distortions due to moral hazard. If the failure to meet the target is associated with a reputation cost, the firm obtains the first best payoff minus the expected value of this cost and platform fees. When reputation costs are high enough, AoN achieves the first best outcome. We also show that AoN Pareto dominates KiA, where the moral hazard problem prevents the firm from investing and committing to deliver the product when it does not raise enough funds.

Our model delivers empirical predictions that are consistent with a number of existing empirical findings. For example, we provide a rationale for frequently over-subscribed successful campaigns, the higher success rate associated with shorter campaigns, and investment made by a number of firms after failed AoN crowdfunding campaigns. We suggest additional testable empirical predictions regarding the relationships between firm characteristics, prior beliefs, targets, success rates and prices. We discuss the robustness of our main findings to variable costs and uncertainty about the firm’s ability to develop their product idea.

Earlier theoretical explanations of reward-based crowdfunding have focused on backer preferences rather than learning and moral hazard. For example, Belleflamme, Lambert, and Schwienbacher (2014) assume that participation in crowdfunding provides backers with an additional utility compared to their valuation for the product, which enables firms to raise funds and to price-discriminate. Varian (2013) endogenizes this additional utility by deriving an equilibrium in which the seemingly altruistic preferences of backers are due to each of them having a pivotal role in ensuring that the firm has enough funds to invest and to produce the product that the backer values. Yet, these important consumer side effects cannot explain some important patterns of successful crowdfunding campaigns, such

⁸With both schemes the firm sets a target before the campaign starts. With AoN, the funds are passed on the firm only if the target is met and returned to backers otherwise, while with KiA the funds raised are always passed on to the firm. While Kickstarter uses AoN, Indiegogo allows firms to choose between AoN and KiA.

as products being sold at par or at a discount, and the fact that many products are oversubscribed multiple times over the target.

We emphasize the importance of learning about demand as an essential reason why firms engage in reward-based crowdfunding. While news articles and research on this topic often consider financial constraints to be the main reason for crowdfunding, recent empirical evidence suggests otherwise (Xu, 2016). Further, in their survey of firms that had both successful and unsuccessful crowdfunding campaigns on Kickstarter, Mollick and Kuppuswamy (2014) find that the respondents reported learning about demand to be the single most important motive for crowdfunding, well ahead of funding that was only the fourth motive. In addition, they report that 30% of the firms that failed to meet their funding target still completed their project, an observation that is consistent with the predictions of our model.⁹

The argument that pre-selling enables firms to learn about backer preferences is also emphasized in Strausz (2016) and Ellman and Hurkens (2016). Importantly these papers contribute to the debate on the importance of moral hazard - in Strausz (2016) moral hazard is so severe that only financially constrained firms with low investment costs crowdfund projects. Ellman and Hurkens (2016) abstract from moral hazard by arguing that reputation costs are high, and emphasize price discrimination instead. In contrast to ours, these two papers assume that the distribution from which individual consumer preferences is drawn is public information, so that uncertainty about demand is restricted to the number of potential consumers in a fixed population. This implies that observing the decisions of a subsample of consumers does not reveal any new information about the preferences of the population of future consumers. Hence, the optimal mechanisms they derive do not allow for the possibility that crowdfunding enables firms to obtain a proof or concept from a small sample, which in turn creates a substantial real option value and mitigates moral hazard.¹⁰ Indeed, in contrast to our findings, Strausz (2016) argues that moral hazard creates large inefficiencies and it would be beneficial to restrict information that the firm obtains from a crowdfunding campaign. Our paper highlights

⁹Cumming, Leboeuf, and Schwienbacher (2014) provide evidence consistent with the idea that All-or-Nothing schemes dominate Keep-it-All schemes. Both Mollick (2014), and Agrawal, Catalini and Goldfarb (2015) analyze the determinants of the success probability of crowdfunding, including the importance of geography. These papers have also found a negative correlation between campaign duration and success probability, which is consistent with our model.

¹⁰In particular, the binomial distribution in these papers is precisely equivalent to the limit where the variance of prior uncertainty about the share of high valuation consumers converges to zero in our setting, i.e., this share is known. In this special case, there is no possibility of Bayesian updating and the real option value of learning is zero.

that such policy would be harmful as it would reduce the real option value of learning and increase the difficulty in overcoming moral hazard. Furthermore, the real option value of learning ensures that firms that benefit most from crowdfunding are indeed those with high demand uncertainty and substantial fixed costs, such as the technology; design and games categories. Finally, Chang (2016) considers a setting in which backers do not know their own valuation and all agents assign common value to rewards about which they obtain noisy signals. This common value assumption is best suited to financial rather than reward-based crowdfunding. Our empirically testable implications also suggest ways to test our model against these alternative theories.¹¹

Our paper also contributes to the literature that points out that investing in entrepreneurial projects enables firms to experiment new technologies (Hellmann 2002, Gromb and Scharfstein 2005, Bettignies and Chemla 2008, Kerr, Nanda, and Rhodes-Kropf 2014). We show that crowdfunding is an efficient mechanism to learn about demand without experimentation costs. We argue that the real option to invest if demand is high enough is sufficient for an entrepreneur to learn about demand, leading to products better attuned to backer preferences. Crowdfunding further appears to improve accessibility to entrepreneurship.¹²

More generally, our paper relates to the strands of corporate finance and monetary economics that view asymmetric information and moral hazard as major sources of financial constraints (Myers 1977, Stiglitz and Weiss 1981, Hart 1995, Tirole 2006).¹³ In our setting with similar frictions, crowdfunding and traditional forms of financing appear to be complements. Whether or not the firm is credit constrained only matters at the investment stage. The campaign itself may either provide actual funding or alleviate the root causes of financial constraints. For example, if financial constraints are driven by asymmetric information about demand, then the crowdfunding campaign that generates public information about demand

¹¹For example, large, financially unconstrained corporations such as Sony have crowdfunded projects. These projects can then lead to the development of new products that can be either spawned or retained (Habib, Hege, and Mella-Barral 2013). Our model also suggests a way to test the existence and magnitude of reputation costs.

¹²Our paper also relates to the industrial organization literature on pre-selling (Tirole, 1988, Rob, 1991, Crawford and Shum, 2005, Chu and Zhang, 2011), which primarily focuses on the firm's opportunity to price-discriminate. While this literature focuses on pre-selling existing products, we focus on the value of pre-selling at an earlier stage of the product cycle, while the product is still being developed and the firm's major fixed investment decisions can still be altered.

¹³In addition, the need for financial intermediaries stems from these and search frictions that complicate the direct interactions between firms and consumers (Wicksell 1934, Townsend and Wallace 1987, Kiyotaki and Moore 2002)

alleviates these constraints.¹⁴ If a firm and its future consumers can overcome moral hazard, then the firm's participation in crowdfunding may also alleviate the same moral hazard problem faced by traditional outside financiers. There are reported cases where firms, after succeeding in reward-based crowdfunding, obtain further financial resources from angels, venture capitalists or investor-based crowdfunding.¹⁵ Relatedly, investor-based crowdfunding highlights the benefits of learning public information from the "crowd" in terms of screening creditworthiness (see Iyer et al 2015).¹⁶

2 The Model

We consider a three-date model in which a firm has a new product idea, and can learn about demand after observing consumer decisions at date 0. At date 1, the firm updates its beliefs and decides whether or not to invest $I \geq 0$. At date 2 it produces and sets price p_2 at which it sells the product to consumers. For now, the firm's marginal cost of production is zero. All agents are risk neutral and discount future cash flows at rate $\delta < 1$. We do not impose exogenous financial constraints.

The firm's potential market consists of N consumers and the firm can sell at most 1 unit of the product to each of them. Each consumer $i \in \{1, \dots, N\}$ has private valuation $v_i = \{0, 1\}$ for one unit of the product and 0 for any additional unit. The fraction θ of consumers with valuation $v_i = 1$ (resp. $v_i = 0$), which we refer to as 1-consumers (resp. 0-consumers), is initially unknown to the firm. Private valuations are conditionally i.i.d, which implies that consumer i 's valuation is a Bernoulli trial drawn from the true distribution, i.e., $\Pr(v_i = 1|\theta) = \theta$. The fraction θ follows a beta distribution, the p.d.f. of which is

$$f(\theta) = \frac{\theta^{\alpha-1} (1-\theta)^{\beta-1}}{B(\alpha, \beta)}, \quad (1)$$

where α, β are positive parameters and $B(\alpha, \beta)$ is the beta function. Beta dis-

¹⁴Further, making information about consumer preferences public can alleviate information asymmetry in an unbiased manner. In contrast, when information is revealed publicly through the actions of privately informed entrepreneurs, it may distort both the market value of the firm and investment decisions. For example, Myers and Majluf (1984) argue that equity issuance decisions convey negative information to investors, and Tinn (2010) and Angeletos, Lorenzoni and Pavan (2010) show that technology investments can be perceived as a positive public signal.

¹⁵Brunstein, Joshua, 2014, "How Kickstarter turned into the Venture Capitalist's Best Friend?", Bloomberg Business, August 11, <http://www.bloomberg.com/bw/articles/2014-08-11/kickstarter-successes-pivot-from-crowdfunding-to-venture-capital>

¹⁶Hildendbrand, Puri, and Rocholl (2015) examine the incentives of borrower group leaders on Prosper.com, a debt-based crowdfunding platform.

tributions enable us to capture different distributions of prior beliefs, be they U-shaped, hump-shaped, or uniform.¹⁷ For the sake of clarity, we write $\alpha = \theta_0 \lambda$ and $\beta = (1 - \theta_0) \lambda$, where $\theta_0 \in [0, 1]$ and $\lambda > 0$, such that

$$\begin{aligned}\mathbb{E}[\theta] &= \frac{\alpha}{\alpha + \beta} = \theta_0 \\ \text{Var}[\theta] &= \frac{\alpha\beta}{(\alpha + \beta)^2(\alpha + \beta + 1)} = \frac{\theta_0(1 - \theta_0)}{(\lambda + 1)}.\end{aligned}$$

That is, θ_0 is the prior mean and a higher λ implies a lower level of uncertainty based on prior beliefs. All agents know the prior distribution. Consumer i knows his own valuation for the product.¹⁸

We first assume that consumers truthfully, costlessly reveal their preferences and explore a benchmark setting where the firm can frictionlessly learn the preferences of a subset $M \leq N$ backers at date 0, e.g., by asking them to respond to a survey.¹⁹ We then relax this assumption and argue that reward-based crowdfunding provides consumers with credible incentives to truthfully reveal their preferences: While 0-consumers never pre-order the product at a positive price ($p_0 > 0$), 1-consumers pre-order it as long as p_0 is not strictly higher than the opportunity cost of waiting and not receiving the product. We keep M fixed to compare the benchmark setting and the crowdfunding model.

Figure 1 summarizes the timing of events under the main crowdfunding model and the appropriate benchmark.

Our model of crowdfunding captures the main real world features of crowdfunding. There are two common types of crowdfunding schemes. The most common one is all-or-nothing (AoN) where the firm sets a target $p_0 \bar{m}'$ and the funds are passed on to the firm if, and only if, the firm meets its funding target $p_0 m \geq p_0 \bar{m}'$, where $m \in \{0, 1, \dots, M\}$ is the number of consumers who pre-order the product. The keep-it-all (KiA) scheme is similar, with the exception that $p_0 m$ is passed on to the firm regardless of whether or not the target is met. We denote $S \in \{Y, N\}$ the outcome of the crowdfunding campaign, where when $S = Y$, the firm's campaign is

¹⁷If parameters $\alpha, \beta \geq 1$ are positive integers, the beta function is given by $B(x, y) = \frac{(x-1)!(y-1)!}{(x+y-1)!}$. More generally, the beta function can be expressed as $B(x, y) = \frac{\Gamma(x)\Gamma(y)}{\Gamma(x+y)}$, where $\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt$ is the gamma function. For example, the prior distribution is uniform when $\alpha = \beta = 1$, and hump-shaped if $\alpha, \beta > 1$.

¹⁸Consumers and firms are assumed to have the same prior beliefs, but our main results would obtain if we relaxed this assumption.

¹⁹For example, consumers may have lexicographic preferences, with primary preferences for the product itself, and secondary preferences for telling the firm that they like the product when asked directly. Then a 0-consumer would only reveal his type if it is costly to for him to deviate and claim to be a 1-consumer.

Figure 1: Timing of main events. Comparison of reward-based crowdfunding and the appropriate benchmark.

successful and meets the target (i.e, $p_0 m \geq p_0 \bar{m}'$); and when $S = N$, the campaign is unsuccessful. We allow the platform to set fees $\varphi_S(m)$ that depend on S and m . Providing intermediation services costs $Z > 0$ and the platform market is assumed to be competitive.

We consider the following reward-based crowdfunding setting:

- Schemes are transparent: during the campaign (afternoon of date 0), participants observe each other's decisions and can withdraw their funds at any time before the end of the campaign. This is akin to a simultaneous move game with perfect information. More formally, when consumer i decides whether or not to pre-order the product, he observes $\{m_{-i}, p_0, \bar{m}'\}$, where m_{-i} denotes the

number of other consumers who back the project. Provided all 1-consumers participate in equilibrium, it is clear that $m = m_{-i} + 1$ if i is a 1-consumer and $m = m_{-i}$ if i is a 0-consumer. Whereas the effect of i on m enables us to incorporate Varian’s (2013) argument about pivotal consumers, being pivotal need not drive consumer decisions.

- Firms obtain funds before they decide whether or not to invest (evening of date 0). This timing discrepancy is the source of moral hazard: firms have a choice between investing and producing or diverting $p_0 m$.
- While they are not necessary, we examine the role played by reputation costs $\chi_S \geq 0$. To this end, we denote χ_Y the cost of not delivering the product in spite of a successful campaign, which may be interpreted as a mere reputation cost, e.g., of being shamed on social media, or as an expected cost of litigation. In turn, χ_N captures the cost of a failed campaign if the firm pursues the project: it reflects either the risk that initially interested consumers lose their interest in the product, or the greater difficulty for a firm to obtain funding from other sources after a failed campaign. For the sake of clarity, we present the results for constant reputation costs. However, all our results hold when reputation costs depend on m .²⁰

These assumptions reflect the common features adopted by prominent reward-based crowdfunding platforms such as Kickstarter and Indiegogo.

3 Benchmark and the value of learning

3.1 Updated beliefs

In this benchmark setting, we assume that at date 0 the firm directly learns the preferences of a sample M of potential consumers. We denote $m \in \{0, 1, \dots, M\}$ the number of 1-consumers within the sample M .

After the firm observes m , it updates its expectations about the share of 1-consumers in the entire population, N . Since $v_i|\theta$ is a Bernoulli trial, $m|\theta$ follows the binomial distribution

$$\Pr(m|\theta) = \binom{M}{m} \theta^m (1 - \theta)^{M-m}. \quad (2)$$

²⁰It is sufficient for all results to hold that χ_Y is non-decreasing function of m (which is realistic, as higher number on dissatisfied participants are likely harm the firm more through the site and social media); and if χ_N is either non-increasing in m or if increasing, then the sensitivity of χ_N with respect to m is not too high.

Bayes' rule implies

$$f(\theta|m) \propto \Pr(m|\theta) f(\theta) \propto \theta^{\lambda\theta_0+m-1} (1-\theta)^{\lambda(1-\theta_0)+M-m-1}$$

and the posterior distribution is also Beta, with

$$\theta|m \sim Be(\lambda\theta_0 + m, \lambda(1-\theta_0) + M - m).$$

Therefore, the posterior expectations are

$$\mathbb{E}[\theta|m] = \frac{\lambda\theta_0 + m}{\lambda + M}. \quad (3)$$

Updated expectations of the share of 1-consumers in the full population is monotonically increasing m . Such Bayesian learning is the source of real option value of learning we discuss later, e.g., when $\frac{m}{M} > \theta_0$ the firm learns that there are more 1-consumers in its potential market than it expected based on its prior beliefs.

To determine the expected value of learning at date 0, we specify the distribution of m . As shown in (2) m is conditionally binomial, with θ unknown and drawn from $\theta \sim Be(\lambda\theta_0, \lambda(1-\theta_0))$. From (1) we obtain

$$\begin{aligned} q_m &\equiv \Pr(m) = \int_0^1 \Pr(m|\theta) f(\theta) d\theta \\ &= \binom{M}{m} \frac{B(\lambda\theta_0 + m, \lambda(1-\theta_0) + M - m)}{B(\lambda\theta_0, \lambda(1-\theta_0))}. \end{aligned} \quad (4)$$

The shape of the beta-binomial distribution replicates the shape of the underlying prior beta distribution.²¹ Unconditional central moments of the beta-binomial variable can be written

$$\mathbb{E}[m] = M\theta_0 \text{ and } Var[m] = M(\lambda + M) Var[\theta] = \frac{M(\lambda + M)\theta_0(1-\theta_0)}{(\lambda + 1)}. \quad (5)$$

The expected m is proportional to the prior mean of the share of 1-consumers, θ_0 , and for any $M > 1$, the higher λ , the lower level of uncertainty about both θ and m .

3.2 First best investment decision

At date 2, the firm can only sell its product to 1-consumers at price $p_2 > 0$. Each of these consumers then obtains a surplus $1 - p_2$, and at date 1, the expected firm value is

$$p_2\delta(m + (N - M)\mathbb{E}[\theta|m]) - I,$$

²¹For example, when the prior is uniform, i.e., $\lambda = 2$ and $\theta_0 = \frac{1}{2}$, $\Pr(m) = \frac{1}{M+1}$, i.e. the distribution of m is discrete uniform. If firms prior beliefs are U-shaped (hump-shaped), then the distribution of m , is also U-shaped (hump-shaped).

where m consumers are known to value the product and $(N - M) \mathbb{E}[\theta|m]$ other future consumers are expected to be 1-consumers. It follows immediately that both the firm value and the joint surplus, i.e. the sum of the payoff to the firm and of the consumer surplus, are maximized when $p_2 = 1$. The firm extracts all consumer surplus and invests in all projects that are non-negative NPV based on updated beliefs.

Denoting $\lceil x \rceil$ the ceiling function, i.e. the nearest integer rounded up, we obtain the following proposition:

Proposition 1 *At date 1, the first best investment decision is as follows: If $I < I_0 \equiv \delta \frac{\lambda \theta_0 (N-M)}{\lambda+M}$, then the firm invests regardless of the realization of m . If $I \geq I_0$, the firm invests if, and only if,*

$$m \geq \tilde{m} = \left\lceil \left(\frac{\delta (\lambda + N)}{\lambda + M} \right)^{-1} (I - I_0) \right\rceil. \quad (6)$$

When the firm invests, its NPV is

$$\begin{aligned} D(m) &= \delta m + \delta (N - M) \mathbb{E}[\theta|m] - I \\ &= \delta \frac{\lambda + N}{\lambda + M} m + I_0 - I, \end{aligned} \quad (7)$$

Proof. Follows from (3), the NPV being non-negative at date 1, i.e., $\delta (m + (N - M) \mathbb{E}[\theta|m]) - I \geq 0$, and m being an integer. ■

It will be useful to notice that the unconditional date 1 NPV of the project is

$$\mathbb{E}[\pi_1] = -I + \delta p_2 N \mathbb{E}[\theta] = -I + \delta N \theta_0, \quad (8)$$

the expected value of which at date 0 is $\mathbb{E}[\pi_0] = \delta \mathbb{E}[\pi_1]$. This implies that if the firm cannot learn about demand, it invests if, and only if,

$$I \leq \delta N \theta_0 \quad (9)$$

We will refer to this benchmark firm as *the reference firm*.

3.3 The real option value of learning under the first best scheme

At date 0, the (firm-level) value of learning is the expected value of a firm that has the opportunity to learn about demand minus the expected value of the reference

firm. Recall that the expected firm profit $D(m)$ at date 1 is (7) and the investment threshold is (6). From (5) the unconditional expectation of the date 1 profit is

$$\mathbb{E}[D(m)] = \delta \frac{\lambda + N}{\lambda + M} \mathbb{E}[m] + I_0 - I = N\delta\theta_0 - I,$$

which is equal to the expected profit of the reference firm. Therefore, the expected value of learning about demand is

$$U^I \equiv \delta \mathbb{E}[D(m) | m \geq \tilde{m}] \Pr(m \geq \tilde{m}) - \delta(N\delta\theta_0 - I) \quad (10)$$

$$= -\delta \mathbb{E}[D(m) | m < \tilde{m}] \Pr(m < \tilde{m}) \text{ for } I < \delta N\theta_0$$

$$U^{NI} \equiv \delta \mathbb{E}[D(m) | m \geq \tilde{m}] \Pr(m \geq \tilde{m}) \text{ for } I \geq \delta N\theta_0, \quad (11)$$

where the superscripts "I" and "NI" denote whether or not the reference firm invests. Since $D(m) < (>) 0$ for any $m < (>) \tilde{m}$ and $D(m) \geq 0$ if $m = \tilde{m}$, both U^I and U^{NI} are positive. Further, U^I and U^{NI} represent both the value of learning for the firm and the joint surplus from learning for consumers and the firm.

From (6), the value of learning is positive if, and only if, the firm's investment cost satisfies

$$I_0 < I < I_0 + \delta M \frac{\lambda + N}{\lambda + M}.$$

This guarantees that the investment threshold, $\tilde{m}$, is above 0 and can be met with a positive probability, i.e., $\tilde{m} \in \{1, 2, \dots, M\}$.

Proposition 2 *The value of learning is maximized when $I = \delta N\theta_0$. Further, U^I is increasing in I and U^{NI} is decreasing in I .*

Proof. See Appendix A.2. ■

Proposition 2 shows that a firm that expects to break even based on prior beliefs has most to gain from learning, while the overall relationship between I and the value of learning is hump-shaped. Indeed, the first best investment threshold is (weakly) increasing in I . If $I < \delta N\theta_0$, the firm benefits from avoiding a sub-optimal investment. This benefit increases with the investment cost that it expects to save. If $I > \delta N\theta_0$, the firm benefits mostly because it can learn that investment is worth undertaking, and thus the higher I the lower the returns from the investment. The opportunity to learn about demand provides the firm with a real option.

It is worth noticing that from (6), if $I = \delta N\theta_0$, the optimal threshold is $\tilde{m} = \lceil M\theta_0 \rceil$. Since, from (5), we have $M\theta_0 = \mathbb{E}[m]$, the threshold for firms that have most to gain from learning equals the unconditional expected value of 1-consumers,

i.e. $\tilde{m} = \lceil \mathbb{E}[m] \rceil$. This observation will be useful when we discuss the empirical relevance and testable predictions of our model.

Our setting also enables us to examine the effect of prior uncertainty on the value of learning. With a beta prior, the firm beliefs are fully characterized by the prior mean θ_0 and by λ , which is inversely related to dispersion.

Proposition 3 *Ceteris paribus, the value of learning increases with the degree of prior uncertainty about demand, i.e., it decreases with λ .*

Proof. See Appendix A.3. ■

Proposition 3 shows that firms with U-shaped prior beliefs, i.e., firms that expect their product to be valued either by many or by few consumers, have most to gain from learning. Since novel, creative consumer products (e.g., new technology gadgets) are more likely to be characterized by such belief structures than existing products, we expect innovative firms to benefit most from learning.

Note that at date 0, λ affects the firm value through three channels. First, an increase in uncertainty increases the difference between the firm prior and updated beliefs about the share of 1-consumers, i.e., $|\mathbb{E}[\theta|m] - \mathbb{E}[\theta]| = \frac{|m - M\theta_0|}{M + \lambda}$. Hence, from (7), the expected value of the firm at date 1 is all the higher (resp. lower) as the realized value of m exceeds (resp. is lower than) $\mathbb{E}[m] = M\theta_0$. Second, from equation (6), higher uncertainty may affect the threshold, $\tilde{m}$, at which the firm finds it optimal to invest. Third, the distribution of m with a higher λ second order stochastically dominates the one with a lower λ . Overall, the second order stochastic dominance, which implies that the probability of extreme realizations of m decreases with λ , ensures that the effect of an increase in uncertainty is positive. Both the value of learning and its embedded real option increase with the realization of m . Finally, the effect of λ on the first best investment threshold further enhances the benefit of learning when there is higher uncertainty.

Figure 2 illustrates these comparative statics by plotting the value of learning about demand as a function of λ and I . We consider two possible prior distributions with the same mean ($\theta_0 = \frac{1}{2}$) and different values of λ . We chose $\lambda_1 = 1.5 < \lambda_2 = 50$ so that the distribution with λ_1 is U-shaped and the one with λ_2 is hump-shaped, as illustrated on Panel 1. The figure assumes $\theta_0 = \frac{1}{2}$, $\delta = 1$, $M = 1600$, and $M/N = 0.1$. Firms break even if $I = 8000$ for both $\lambda = \lambda_1$ and $\lambda = \lambda_2$. The value of learning is positive if $I \in (6.7, 15993)$ for $\lambda = \lambda_1$, and if $I \in (218.2, 15570)$ for $\lambda = \lambda_2$. Panel 2 plots the value of learning about demand as a function of I for both λ_1 and λ_2 .

Figure 2: First-best value of learning

4 Learning about demand through reward-based crowdfunding platforms

We now turn to our main model. While a survey may be unlikely to induce consumers to truthfully reveal their valuation, pre-ordering decisions generate credible information as only 1-consumers are willing to pre-order the product at $p_0 > 0$.

We derive an optimal crowdfunding scheme, which involves the firm's choice between an all-or-nothing (AoN) or keep-it-all (KiA) scheme and the choice of a target $\bar{m}'$ and a price p_0 to maximize its expected revenues. Since crowdfunding platforms are perfectly competitive, the expected fee income must equal the cost Z of running the platform, i.e.,

$$\delta \Pr(m < \bar{m}') \mathbb{E}[\varphi_N(m) | m < \bar{m}'] + \delta \Pr(m \geq \bar{m}') \mathbb{E}[\varphi_Y(m) | m \geq \bar{m}'] = Z. \quad (12)$$

From Section 3.3, we know that when $I < I_0$ there is no value of learning, which implies that such firms would choose not to participate in crowdfunding as long as they have alternative ways to finance their investments. We will therefore focus on the case where $I_0 < I < I_0 + \delta M \frac{\lambda+N}{\lambda+M}$. The firm knows M , which is determined by the length of the campaign. It is intuitive that an optimal scheme must induce all 1-consumers to reveal their valuations by pre-ordering the product. We will start by analyzing the schemes separately. In either case we need to derive the subgame perfect Nash equilibrium by backward induction. We then compare the schemes and derive the firm's utility under the optimal scheme.

4.1 All-or-Nothing scheme

It is clear that at date 2 it remains optimal for the firm to extract all consumer surplus, i.e., $p_2 = 1$. Let us consider that the crowdfunding stage is informative, i.e., m out of M consumers pre-order the product at date 0. We can then derive that the date 1 investment is worth

$$\pi_1 = \frac{p_0 m}{\delta} + \delta (N - M) E[\theta|m] - I = \left(\frac{p_0 m}{\delta} - \delta m \right) + D(m), \quad (13)$$

where $D(m)$ is defined in (7). There are two incentive compatibility conditions, which determine the firm's investment decision at date 1:

$$\left(\frac{p_0 m}{\delta} - \delta m \right) + D(m) - \varphi_Y(m) \geq \frac{p_0 m}{\delta} - \chi_Y - \varphi_Y(m) \text{ if } S = Y \quad (14)$$

$$D(m) - \chi_N - \varphi_N(m) \geq -\varphi_N(m) \text{ if } S = N \quad (15)$$

It is clear that fees do not affect the firm's date 1 investment decision in either state. Further, the pre-ordering price, p_0 , does not affect incentive compatibility in either state. In state $S = Y$, the condition (14), simplifies to:

$$\delta (N - M) \mathbb{E}[\theta|m] - I + \chi_Y \geq 0. \quad (16)$$

The expected sales to new consumers and reputation costs give the firm incentives to invest and deliver the product. Condition (15) highlights that the firm may have an incentive to invest even though its crowdfunding campaign does not meet the target.

From the expression for $D(m)$ in (7), the firm invests if, and only if

$$m \geq \bar{m}_{YA} = \left\lceil \frac{\lambda + M}{N - M} \left(\frac{I - \chi_Y - I_0}{\delta} \right) \right\rceil \text{ if } S = Y \quad (17)$$

$$m \geq \bar{m}_{NA} = \left\lceil \frac{\lambda + M}{\lambda + N} \left(\frac{I + \chi_N - I_0}{\delta} \right) \right\rceil \text{ if } S = N. \quad (18)$$

Since the firm's investment decision is independent of p_0 , and the firm's date 1 profit is monotonically increasing in p_0 , the firm sets the price as high as possible (provided that rational consumers are willing to participate).

During the afternoon of date 0, each consumer decides whether to pre-order the product, wait or not participate. Because the firm extracts all consumer surplus at date 2, the expected utility of waiting is zero. Each consumer i observes other consumers' decisions and anticipates the firm's investment decision in date 1, i.e., a consumer with v_i pre-orders the product if, and only if

$$(\delta^2 v_i \Pr(m \geq \bar{m}_{YA} | m, \bar{m}', m \geq \bar{m}') - p_0) \Pr(m \geq \bar{m}' | m, \bar{m}') \geq 0.$$

Clearly, 0-consumers do not have incentives to participate. The all-or-nothing scheme insures consumers against the firm not meeting the target. Although it does not insure consumers against the risk of non-delivery conditional on the target being met, consumers can compare $\bar{m}_{YA}$ and $\bar{m}'$, which enables them to coordinate and not to give funds to a firm unless $m \geq \bar{m}_{YA}$. This is made possible by the transparent nature of all-or-nothing crowdfunding which allows consumers to observe total pledges made during the campaign and withdraw their pledges during the campaign. It is then follows that the firm can not benefit from setting $\bar{m}' < \bar{m}_{YA}$. When $\bar{m}_{YA} \geq \bar{m}'$, it holds that $\Pr(m \geq \bar{m}_{YA} | m, m \geq \bar{m}') = 1$, the firm can pre-sell at a minimum discount, $p_0 = \delta^2$, and 1-consumers do not need to actively coordinate in the equilibrium.

Denoting $\bar{m}_A'^*$ the equilibrium target and $\bar{m}_A^*$ the investment threshold, we obtain the following Proposition describing the firm's decision. Recall also the first best investment threshold $\tilde{m}$, defined in (6).

Proposition 4 *With AoN:*

1) *if both reputation costs are small, i.e.,*

$$\chi_Y + \chi_N \frac{N - M}{\lambda + N} < \frac{\lambda + M}{\lambda + N} (I - I_0), \quad (19)$$

then $\tilde{m} \leq \bar{m}_{NA} \leq \bar{m}_{YA}$. The firm sets its target to $\bar{m}_A'^ = \bar{m}_{YA}$, but invests whenever $m \geq \bar{m}_A^* = \bar{m}_{NA}$.*

2) *if the cost of no-delivery is intermediate and the cost of a failed campaign is sufficiently high, i.e.,*

$$\frac{\lambda + M}{\lambda + N} (I - I_0) - \chi_N \frac{N - M}{\lambda + N} \leq \chi_Y \leq \frac{\lambda + M}{\lambda + N} (I - I_0), \quad (20)$$

then $\tilde{m} \leq \bar{m}_{YA} \leq \bar{m}_{NA}$. The firm sets both the target and the investment threshold to $\bar{m}_A'^ = \bar{m}_A^* = \bar{m}_{YA}$.*

3) *If the cost of no-delivery is sufficiently high, i.e.,*

$$\chi_Y \geq \frac{\lambda + M}{\lambda + M} (I - I_0), \quad (21)$$

then $\bar{m}_{YA} \leq \tilde{m} \leq \bar{m}_{NA}$. The first best is achieved and the firm sets the target and the investment threshold to $\bar{m}_A'^ = \bar{m}_A^* = \tilde{m}$.*

Proof. See Appendix A.4. ■

Proposition 4 describes the firm's decisions under different ranges of reputation costs. Part 3 shows that if the reputation cost of no-delivery, χ_Y , is high, AoN can

achieve the first best. The results of Part 1 and 2 with smaller reputation costs, which probably reflect better the current crowdfunding industry, indicate that the firm sets the target higher than the optimal level (6) in order to convince consumers to back the project. Indeed, consumers are aware that the funds the firm receives before it decides whether or not to invest alter its incentives to invest. Hence, they will only back the project if the announced target is high enough. In addition, from (17), an increase in χ_Y alleviates the moral hazard problem.

Further, the target decreases with $N - M$, and it tends to infinity when $M \rightarrow N$. This highlights that in low reputation cost (or weak legal enforcement) environments, pre-selling to **all** future consumers cannot be achieved through reward-based crowdfunding. This highlights an important feature of third-party reward-based crowdfunding platforms: by keeping the campaigns short, they guarantee that only a subset of consumers can pre-order the product because a limited number of potential consumers can participate on time. From (16), it appears that M must be sufficiently low relative to N . Even if $\chi_Y \rightarrow 0$, the firm chooses to invest as long as the updated beliefs about demand for the remaining $N - M$ potential consumers is sufficiently high. We argue that updating beliefs is the key driver that makes reward-based crowdfunding incentive compatible and successful.²² As $\mathbb{E}[\theta|m]$ is increasing in m , campaigns that raise more funds become more likely to deliver rewards.

In contrast, if we did not consider the possibility of updating beliefs, it is clear that as $\chi_Y \rightarrow 0$, the firm would not set the target strategically and would invest if, and only if, $\delta(N - M)\mathbb{E}[\theta] = \delta(N - M)\theta_0 \geq I$. From (8) it then follows that the firm's incentives to invest would be lower after participating in reward-based crowdfunding than before the campaign. Hence, no firm would participate unless crowdfunding were the only possible source of funding.²³

Part 1 of Proposition 4 shows that the firm can also benefit from learning about demand if it does not meet the target. This is consistent with empirical observations that many firms complete the project after an unsuccessful campaign. Investing in state $S = N$ comes at a potential reputation cost χ_N in the case of a failed campaign. From Proposition 4, both firms and crowdfunding platforms benefit from

²²In our setting, the sample M is representative. However, a qualitatively similar result would hold if the share of 1-consumers were larger in M than in the overall population. One would only have to adjust expectations relative to this bias.

²³This is an essential difference with Strausz (2016), who does not consider the updating of beliefs, and confirms that in the absence of the real option feature of crowdfunding, firms would only choose crowdfunding when faced with extreme financial constraints.

increasing the reputation costs associated with no-delivery, χ_Y , and from reducing the reputation costs due to the failure to meet the target, χ_N . This is again consistent with the recent practice of platforms like Kickstarter, which discloses on its website information about past successful campaigns, but not on failed ones.²⁴

Overall, when the platform can keep M low enough and the firm can update its beliefs about demand. AoN crowdfunding is possible and it can achieve the first best when χ_Y is sufficiently high.

4.2 Keep-it-All scheme

The distinct feature of KiA campaigns is that the firm keeps all the funds raised whether or not it meets the target. Unlike AoN, we assume that the firm's failure to deliver the product entails a reputation cost χ_Y whether or not it meets the target. Indeed, under KiA consumers have paid for the product regardless of the target being met. For any S , the firm invests at date 1 if, and only if²⁵

$$D(m) \geq \delta m - \chi_Y, \quad (22)$$

which implies that the firm invests if, and only if,

$$m \geq \bar{m}_K = \left\lceil \frac{\lambda + M}{N - M} \left(\frac{I - \chi_Y - I_0}{\delta} \right) \right\rceil.$$

As before, each consumer i observes other consumers' decisions and anticipates the firm's investment decision at date 1, i.e., an i -consumer pre-orders the product if, and only if

$$\delta^2 v_i \Pr(m \geq \bar{m}_K | m, \bar{m}') - p_0 \geq 0.$$

Even though consumers are not insured against the failure of a campaign, they observe each other's decisions and are able to coordinate and avoid backing a firm that they expect will not invest at date 1. This implies that the firm can still set $p_0 = \delta^2$, and rational consumers will withdraw their pledges if $m < \bar{m}_K$. Unlike AoN, KiA implies that consumers need to coordinate actively in equilibrium. Further, unlike the AoN scheme in which moral hazard is only an issue when the firm meets its target, the KiA scheme always entails a moral hazard problem.

²⁴See e.g., "Kickstarter explains why it hides failures" by Chase Hoffberger (May 31 in The Daily Dot).

²⁵In state $S = Y$, the incentive compatibility condition is the same as with the AoN scheme (e.g., 14), and in $S = N$, it is $(\frac{p_0 m}{\delta} - \delta m) + D(m) - \varphi_N(m) - \chi_N \geq \frac{p_0 m}{\delta} - \chi_Y - \chi_N - \varphi_Y(m)$, both simplify to (22)

The firm's incentive compatibility constraints are exactly the same in both states. Denoting the target and investment threshold with $\bar{m}_K'^*$ and $\bar{m}_K^*$, respectively, we obtain

Proposition 5 *With a KiA scheme,*

1) *if the reputation cost of no-delivery is low, i.e.,*

$$\chi_Y \leq \frac{\lambda + M}{\lambda + N} (I - I_0), \quad (23)$$

then $\tilde{m} \leq \bar{m}_K$. The firm obtains funds and invests if, and only if, $m \geq \bar{m}_K' = \bar{m}_K$. The firm's best response is to set the target to $\bar{m}_K'^ \leq \bar{m}_K^*$*

2) *if the reputation cost of no-delivery is high, i.e.,*

$$\chi_Y > \frac{\lambda + M}{\lambda + N} (I - I_0) \quad (24)$$

then $\tilde{m} > \bar{m}_K$. The firm obtains funds and invests if, and only if, $m \geq \bar{m}_K' = \bar{m}_K$. The firm's best response is to set the target to $\bar{m}_K'^ \leq \bar{m}_K^*$*

Proof. See Appendix A.5. ■

Proposition 5 highlights that the KiA scheme can also elicit incentive compatible reward-based crowdfunding, but fails to achieve the first best even with high reputation costs unless (23) is satisfied with an equality.

Comparing Proposition 5 and Part 2 of Proposition 4, both schemes only yield the same outcome if χ_Y is intermediate and χ_N is high. This suggests that under some parameter values both schemes may indeed coexist.

In general, KiA leads to strictly worse outcomes than AoN. When χ_Y is low, KiA and AoN yield the same outcome after a successful crowdfunding campaign. However, under AoN, the firm may benefit from investing even though its campaign fails because of the value of learning and the absence of moral hazard. If χ_Y is high, then KiA creates another distortion. The firm may be forced to (over-)invest at date 1, simply to avoid high reputation costs. Hence, the firm cannot be worse off by choosing AoN.

Interestingly, the target set in a KiA scheme carries little meaning. If $\chi_N = 0$, the firm can set any target. As long as the failure to meet the target is associated with $\chi_N > 0$, the firm sets any target $\bar{m}_K'^* \leq \bar{m}_K^*$ to minimize this cost. KiA also requires more active monitoring to avoid distributing funds to firms that do not have at least $\bar{m}_K$ 1-consumers.

4.3 Expected value under reward-based crowdfunding

Since when χ_Y is sufficiently high the investment decision achieves the first best, the firm benefits from the real option value of learning minus Z . Low values of χ_Y and χ_N (Part 1 of Proposition 5) are more interesting and more realistic. We have shown that the firm prefers AoN. We can summarize the expected value of participating in AoN:

Proposition 6 *The date 0 expected value of participation in AoN is*

$$\begin{aligned} U^I &= \begin{pmatrix} -\delta \mathbb{E}[D(m) | m < \bar{m}_{NA}] \Pr(m < \bar{m}_{NA}) \\ -\delta \Pr(\bar{m}_{NA} \leq m < \bar{m}_{YA}) \chi_N - Z \end{pmatrix} \text{ if } I < \delta N \theta_0 \\ U^{NI} &= \begin{pmatrix} \delta \mathbb{E}[D(m) | m \geq \bar{m}_{NA}] \Pr(m \geq \bar{m}_{NA}) \\ -\delta \Pr(\bar{m}_{NA} \leq m < \bar{m}_{YA}) \chi_N - Z \end{pmatrix} \text{ if } I \geq \delta N \theta_0, \end{aligned} \quad (25)$$

where $\bar{m}_{NA}$ and $\bar{m}_{YA}$ are given by (18) and (17), respectively. If $\chi_N \rightarrow 0$, then $\bar{m}_{NA} \rightarrow \tilde{m}$.

Proof. See Appendix A.6. ■

Since the firm does not divert funds in equilibrium, χ_Y has no direct effect on the expected payoff to the firm. Further, the first term of U^I and U^{NI} is exactly the one we obtained in the first best benchmark. In addition, if $\chi_N \rightarrow 0$, then the second term is also zero and the comparative statics derived in Section 3.1 apply with the difference that the firm only participates if its real option value of learning is higher than Z . Interestingly, this is true despite the fact that firms are forced to set a high target $\bar{m}' = \bar{m}_{YA} > \tilde{m}$ as shown in Proposition 4 and in equations (6) and (17). The main purpose of a feasible target is to ensure that the platform can cover its operating cost while granting the firm a positive probability of meeting its target. We have also shown that the fee structure does not affect the firm's decisions. Even when $\chi_Y \rightarrow 0$, the platform can ensure that reward-based crowdfunding is possible by keeping the number of participants, M , limited and by guaranteeing transparency.

4.4 Firm characteristics and AoN project funding.

We have shown that even in a low reputation cost environment, the firm can learn about demand through incentive compatible AoN crowdfunding and that the real option value of learning is close to the first best. Even though financial constraints are irrelevant to the crowdfunding target, comparing ex-ante and ex-post funding relative to the investment cost yields insightful results.

For clarity consider a firm subject to the most severe moral hazard problem, i.e., $\chi_Y \rightarrow 0$. First consider the case where the investment cost is $I = I^{BE} = \delta\theta_0 N$, i.e., the firm breaks even based on prior beliefs. As we have shown, this investment cost maximizes the real option value of learning given $\{\theta_0, \lambda\}$, and the firm's incentive to participate in AoN crowdfunding. From $I_0 = \delta \frac{\lambda\theta_0(N-M)}{\lambda+M}$, and (17), this firm sets a target

$$\begin{aligned} m &\geq \bar{m}_{YA}^{BE} = \left\lceil M\theta_0 \frac{N+\lambda}{N-M} \right\rceil \\ &= \left\lceil \frac{M}{N} \frac{I^{BE}}{\delta} \frac{N+\lambda}{N-M} \right\rceil. \end{aligned}$$

The firm must be able to meet its target $\bar{m}_{YA}^{BE}$ with a positive probability, i.e., we must have $\bar{m}_{YA}^{BE} \leq M$. From (17), this holds when

$$\lambda \leq \frac{N(1-\theta_0) - M}{\theta_0}$$

A successful campaign raises enough funds to cover investment needs if

$$p_0 \bar{m}_{YA}^{BE} = \frac{1}{\delta} \bar{m}_{YA}^{BE} \geq I^{BE}.$$

which is satisfied when

$$I^{BE} \frac{M}{N} \frac{N+\lambda}{N-M} \geq I^{BE} \iff \lambda \geq \frac{N(N-2M)}{M} \quad (26)$$

Since $\lambda > 0$, if the campaign does not reach out to more than half of the potential consumers, a successful campaign does indeed cover the investment cost as long as the target is feasible, i.e. $\bar{m}_{YA}^{BE} \leq M$. This is realistic given the short duration of campaigns. Further, as λ increases, so does the real option value of learning, and the firm may be able to reach more than half of its consumers at the cost of a higher threshold. Hence, AoN funds the firm's investment. Further, this firm would likely have better access to external funding after a failed campaign with $\bar{m}_{YA} > m > \bar{m}_{NA}$. While it was merely breaking even based on prior beliefs, it now has a strictly positive NPV for a wide range of parameters.

More generally, now consider an investment cost $I = I^{BE} + \Delta$. The firm sets the target

$$\begin{aligned} m &\geq \bar{m}_{YA} = \left\lceil M\theta_0 \frac{N+\lambda}{N-M} + \frac{\Delta}{\delta} \frac{\lambda+M}{N-M} \right\rceil \\ &= \left\lceil \frac{M}{N} \frac{I^{BE}}{\delta} \frac{N+\lambda}{N-M} + \frac{\Delta}{\delta} \frac{\lambda+M}{N-M} \right\rceil \\ &= \left\lceil \frac{M}{N} \frac{I^{BE} + \Delta}{\delta} \frac{N+\lambda}{N-M} + \frac{\Delta}{\delta} \frac{\lambda}{N} \right\rceil \end{aligned}$$

For the firm to be able to meet the target with a positive probability,

$$\lambda \leq \delta \frac{(N(1 - \theta_0) - M)M}{\delta M \theta_0 + \Delta} - \frac{\Delta M}{\delta M \theta_0 + \Delta}$$

When $\Delta > 0$, the firm would not invest based on prior beliefs, and since the project has a negative NPV based on prior beliefs, the firm should not obtain outside financing. However, when $\chi_Y = 0$ and when (26) is satisfied, this firm can successfully raise enough funds through crowdfunding in order to cover its investment cost. Hence, among the firms that should not obtain funding in a frictionless capital market, the firms that benefit most from AoN crowdfunding are also most likely to be able to fund their project entirely through successful AoN crowdfunding.

Finally, a firm with a positive NPV project based on prior beliefs (i.e., $\Delta < 0$) and with high reputation costs is likely to set a target that does not cover its investments needs. Indeed, this firm can set a lower target that guarantees incentive compatibility. While, in our model, the firm can do so as it has frictionless access to external funding, it can also realistically be expected to not be financially constrained.

5 Discussion and extensions

Role of third-party platforms In Section 4, we have shown that the first best characterized in Section 3 can nearly be achieved by AoN. But when are third-party platforms needed? Are features such as transparency optimal? In Online Appendix B, we allow the firm to design its own pre-selling scheme, and to pre-commit to it. As one would expect, the first best can be achieved with full insurance, i.e., full money-back guarantees, in the case of no-investment. However, we prove that in the environment where the firm's ability to offer such insurance is limited, the firm would indeed choose to pre-commit to transparency and to a limited M . This shows the rationale for third-party platforms. Both transparency and limited M are features that many firms are unable to commit to on their own. This is because another moral hazard problem would arise: when the firm's pre-ordering scheme lacks interest, the firm may learn that it is sub-optimal to invest. The firm then still has incentives to divert as many funds as possible, which can be achieved by keeping the pre-ordering possibility ongoing and/or by overstating the number of consumers that have pre-ordered. Hence, reward-based crowdfunding benefits firms

that cannot credibly, directly pre-commit to deliver the product and that need a third-party to facilitate commitment.

Variable costs In the main model we considered zero variable costs. Suppose instead that a fixed cost I_F is paid at date 1 and a variable cost $I_V \in (0, 1)$ is paid at date 2. As in the main setting, the highest price at which the firm can pre-sell the product is $p_0 = \delta^2$. Then the date 1 expected profit is

$$\delta \frac{\lambda + N}{\lambda + M} m (1 - \delta I_V) + I_0 (1 - \delta I_V) - I_F.$$

Writing $I \equiv \frac{I_F}{(1 - \delta I_V)}$, the date 1 profit equal to

$$(1 - \delta I_V) D(m),$$

where $D(m)$ is as in (7). The first best investment threshold is the same as the one derived in Section 3 and all comparative statics regarding this remain valid. Since I is increasing in I_V , an increase in the variable cost increases the threshold at which the firm is willing to invest.

Reasoning as in Section 4, the firm has incentives to invest at date 1 under AoN if, and only if

$$\begin{aligned} D(m) &\geq \frac{\delta m - \chi_Y}{(1 - \delta I_V)} \text{ if } S = Y \\ D(m) - \frac{\chi_N}{(1 - \delta I_V)} &\geq 0 \text{ if } S = N \end{aligned}$$

When diverting funds, the firm now also avoids the variable cost. The thresholds can be written

$$\begin{aligned} \bar{m}_{YA} &= \left\lceil \left(\frac{N - M}{\lambda + M} - \frac{\delta I_V}{1 - \delta I_V} \right)^{-1} \left(\frac{I_F - \chi_Y - I_0}{\delta (1 - \delta I_V)} \right) \right\rceil \\ \bar{m}_{NA} &= \left\lceil \frac{\lambda + M}{\lambda + N} \left(\frac{I_F + \chi_N}{\delta (1 - \delta I_V)} - \frac{I_0}{\delta} \right) \right\rceil. \end{aligned}$$

The variable cost increases the thresholds for investment in both states. Further, the threshold $\bar{m}_{YA}$ increases too. Intuitively, the variable cost increases the severity of the moral hazard problem, which increases the difficulty of crowdfunding. This implies that firms with high variable costs relative to fixed costs are likely to find it difficult to participate and benefit from crowdfunding. All the other results in the preceding sections remain.

Uncertainty We assumed that whenever the firm invests, it will succeed to produce the product. Suppose instead that the investment leads to success with

probability $\gamma \in (0, 1]$. Hence, the firm's date 1 profit is

$$\frac{\lambda + N}{\lambda + M} \frac{p_0}{\delta} m + \gamma I_0 - I.$$

In addition, the consumers who pre-order the product know that they will receive it with probability γ only. Hence, they are willing to buy if, and only, if $p_0 \leq \delta^2 \gamma$. The firm has to offer a larger discount in order to convince consumers to participate and sets $p_0 = \delta^2 \gamma$. The new value of (7) is then

$$\gamma \left(\delta \frac{\lambda + N}{\lambda + M} m + I_0 - \frac{I}{\gamma} \right).$$

This implies that all our qualitative results remain valid. In particular the first best investment threshold and the value of learning are the same as in Section 3, with the only difference being that we substitute I/γ for I . The results of Section 4 also remain similar, with investment thresholds with an AoN scheme satisfying:

$$\begin{aligned} \bar{m}_{YA} &= \left\lceil \frac{\lambda + M}{N - M} \left(\frac{I - \chi_Y}{\gamma \delta} - I_0 \right) \right\rceil \\ \bar{m}_{NA} &= \left\lceil \frac{\lambda + M}{\lambda + N} \left(\frac{I + \chi_N}{\gamma \delta} - \frac{I_0}{\delta} \right) \right\rceil. \end{aligned}$$

The uncertainty about the firm's ability to deliver the product increases the thresholds.

A risk of delayed delivery would yield similar results. It would also increase both the discount that the firm would need to offer at the pre-selling stage and the investment thresholds.

Overall, both uncertainty about the firm's ability to deliver the product and variable costs imply higher investment thresholds, which implies that successful crowdfunding will be more difficult. The intuition for these effects is simple, as both imply lower expected payoffs to the firm. In addition, uncertainty about the firm's ability to deliver the product implies that the firm must offer consumers larger discounts at the pre-selling stage.

6 Empirical implications

In this section we highlight empirical facts and several testable implications of our model. Our discussion relates to recent empirical work as well as to the information that we have collected from Kickstarter on all the projects successfully funded in the Technology and Theatre categories from January 1, 2015 to September 17, 2015.

These categories are informative as they represent opposite ends of the spectrum of available project types. While the technology category is the one most directly related to our model, the theatre category enables us to discuss our findings in the light of other project categories. It is worth noting that in theatre projects, rewards are generally consumer products such as tickets to a show or to a rehearsal.

1) Importance of learning about the demand.

In our model, the firms that choose to pre-sell a product update their beliefs in Bayesian fashion following pre-ordering decisions made by rational consumers. This is consistent with the empirical findings in Xu (2016) that finds evidence of this based on Kickstarter data from 2009 to 2012. In addition, Mollick and Kuppaswamy (2014) survey technology, project design, and video games firms that successfully and unsuccessfully crowdfunded projects on Kickstarter from 2009 to 2012. Their survey results show that the number one reason why both successful and unsuccessful firms sought crowdfunding was "to see if there is demand for the project" (68% and 60% of successful and unsuccessful projects agreeing, respectively). Financing the project was only the fourth reason cited, while demand-related marketing and connecting with community were ranked second and third, respectively.

2) Successful projects often raise funds over the target

In our learning-based model, the properties of expectations imply that $\mathbb{E}[m|m \geq \bar{m}] > \bar{m}$. As different firms set different prices, the corresponding empirically observable equivalent is $\mathbb{E}\left[\frac{pm}{p\bar{m}}|pm \geq p\bar{m}\right] > 1$, where pm are the funds raised and $p\bar{m}$ is the target. In 2015, our data indicate that the average successful US-based technology project raised 5.8 times its target, while an average successful US-based theatre project raised 1.3 times its target. Appendix A.7 plots the full distribution of $\Pr\left(\frac{pm}{p\bar{m}} < x|pm \geq p\bar{m}\right)$ in both categories based on these 2015 data. Over-pledging in successful projects appears to be the rule rather than the exception, especially in the technology category. Our model differs from the existing alternative explanations in that respect. If crowdfunding was primarily about participants helping a credit constrained firm to raise enough funds in order to invest (see Strausz, 2016), or about being pivotal in ensuring that a likeable product exists (see Varian, 2013), we should not observe systematic over-pledging. Varian's model allows for over-pledging, but only to the degree that each pivotal individual wants to obtain the full gift for his contribution, the amount of which can exceed the target. This could

explain some over-pledging, but not the magnitude of over-pledging observed, especially for technology projects. While we observe systematic, massive over-pledging, there exists a view that with the exception of a few most successful projects, most projects succeed small and fail big (see Mollick 2012). Our model and our preliminary evidence suggest that one should relate the degree of over-pledging to the characteristics of the project. Statistically we expect over-pledging to increase with project uncertainty, e.g. it should be higher in technology than in theatre projects, which is consistent with our illustration. We argue that most profitable projects should systematically succeed big, even though they also fail more often.

3) If the moral hazard problem is severe, firms set the target too high.

In the introduction, we have discussed the theoretical debate about the severity of moral hazard, and the question whether reputation costs are high enough to eliminate this concern. Our model provides a structure to test the severity of moral hazard and/or the importance of reputation costs, but requires a few steps to build the logic. We have shown that with the optimal contract, the firms that benefit most from pre-selling the product are those that would break even without crowdfunding. These firms set the target such that $\mathbb{E} \left[\frac{pm}{pm} \right] = 1$, i.e., a break even firm sets the target such that it expects to meet the target without exceeding it. If the set of firms that engage in crowdfunding were able to set the optimal target, we would expect firms to set varying targets with $\mathbb{E} \left[\frac{pm}{pm} \right] = 1$ on average. However, we show that when the enforcement of the delivery of the product is limited, we must have $\mathbb{E} \left[\frac{pm}{pm} \right] < 1$ because firms must set a more ambitious target. The latter appears to be supported by preliminary empirical evidence, based on back of the envelope calculations. Cumming et. al. (2015) analyze AoN and KiA projects at Indiegogo, and report an average completion ratio, $\frac{pledges}{goal} = \frac{pm}{pm}$, of 0.403, ranging from 0.337 to 0.617 across innovative, creative, and social categories and with both KiA and AoN schemes. This suggests that a typical target is about twice as high as the optimal target for the firms that have most to gain from pre-selling a new product. Our own data from Kickstarter 2015 suggests that $\mathbb{E} \left[\frac{pm}{pm} \right]$ is 0.95 for technology and 0.45 for theatre projects. While this suggests that technology projects may involve higher reputation costs than theatre projects, further empirical analysis is needed to establish further evidence. Overall, these stylized facts indicate that moral hazard is not negligible.

4) Relationship between firm characteristics and crowdfunding

Our model provides a clear parametric statistical structure that can be used to analyze the firm’s prior beliefs based on the realized data. One of our predictions is that greater uncertainty makes projects and participation more profitable. In Appendix A.7 we construct the full distribution of $\frac{pm}{\bar{pm}}$ for technology and theatre project. The data is consistent with the intuition that technology projects are riskier than theatre projects in the sense of second order stochastic dominance. In the context of our model, this explains why technology firms participate more often (7/1 ratio for live projects) and raise more money on average than theatre firms. This is also consistent with Xu (2016), who shows that the firms that face more uncertainty are those that continue to participate in reward-based crowdfunding after the terms of their funding have been improved.

Our model can also shed light on the link between funding targets and firm characteristics, e.g., investment costs, variable costs and project types. In addition, the main distributional parameters of the prior (the parameters of beta distribution) could also be estimated using project data. This enables future researchers to see how prior beliefs differ across different categories and project sizes.

5) *Post-crowdfunding stage*

Our results predict that many firms crowdfunding a project through an All-or-Nothing scheme will keep pursuing their project. This is consistent with the observations made by Mollick (2014) who presents survey results showing that many firms continue to pursue their projects even though they fail to meet their target. In our model, consumers are rational with standard preferences, so we predict that there should be a discount rather than a premium at the crowdfunding stage. While we do not have enough data to test this, anecdotal evidence based on firms’ announced retail price or on examples such as Pebble Watch suggests that this is the case. With more systematic data, our predictions could be tested as alternatives to those in Belleflamme et. al. (2013) who explain crowdfunding as a means to price-discriminate individuals who enjoy the crowdfunding experience. In contrast to our model, their results imply that the prices would be set at the crowdfunding stage at a premium over the retail price. The relationship between pre-selling prices and retail prices could also shed light on what type of campaigns are price-discriminating instruments and what campaigns intend to learn about demand and to provide firms with a real option.

7 Conclusion

This paper developed a model in which reward-based crowdfunding platforms enable firms to pre-sell a product they may wish to develop and to learn whether there is enough demand for it. This in turn enables firms to make more informed investment decisions, and is most beneficial for firms that face sufficiently high demand uncertainty and investments costs. The relationship between investment costs and the value of crowdfunding is inverted U-shaped.

We showed that all-or-nothing crowdfunding schemes are not only more efficient than keep-it-all schemes, but also nearly as efficient as a frictionless consumer survey where individuals truthfully reveal their preferences. This is in spite of backers being exposed to the risk of the firm diverting funds after the campaign. Rational backers overcome this friction by coordinating not to back firms that they expect to have insufficient incentives to invest. We show that because of the real option value of learning, projects that raise more funds give firms greater incentives to invest instead of diverting funds. In equilibrium, the firm sets a sufficiently ambitious target to reassure backers that the firm will invest. As a result, the firm can offer consumers the possibility to pre-order the product at a minimal discount. Setting a target that is higher than the first-best investment threshold does not necessarily hurt the firm, as firms benefit from learning and may choose to invest even after a failed crowdfunding campaign.

Further, we show that firms that can pre-commit to a full-money back guarantee do not need third-party platforms. Instead, they can offer consumers the possibility to pre-order products on their own website. This is consistent with pre-orderings available on the websites of well established corporations such as iTunes and travel agencies. However, most firms are less known and cannot pre-commit to money-back guarantees. Third-party crowdfunding platforms bring value to these firms because they facilitate commitment to abide by features that overcome moral hazard. We show that a limited length of campaigns and transparency are sufficient to make pre-selling campaigns incentive compatible. Further, firms that cannot credibly commit to money-back guarantees would like to pre-commit to these contractual features but find it difficult. In addition, other mechanisms such as stronger legal enforcement would enable firms to alleviate moral hazard further. While these recommendations are natural in our model, they may entail further incentive problems. For example, stronger legal enforcement would discourage firms that face innovation uncertainty from participating in crowdfunding.

More broadly, we argue that reward-based crowdfunding overcomes a set of traditional frictions by enabling firms and consumers to interact directly. Our model also suggests that the direct interactions provided by internet websites and social media, which are widely used to build reputations but may also entail reputation costs, have enabled crowdfunding platforms to develop. Our argument suggests that learning about demand is facilitated by reward-based crowdfunding: While investor-based crowdfunding relies on investors forming beliefs about the firm's sales and cash flows, common transparent reward-based crowdfunding relies on each consumer making backing decisions based on his own valuation.

In our model, the only parameter the firm can learn about is total demand. In reality, the benefits can extend to learning about consumer preferences about the specifications of the product, e.g., the color of the Pebble watch or the features of a new game. We argue that to fully understand the success of reward-based crowdfunding, it is important to consider its role as a learning device, rather than focusing on a mere funding scheme. Our model can explain the following stylized facts: 1) a noticeable proportion of firms that fail to meet their target in a crowdfunding campaign still complete the project, 2) many successful projects receive amounts noticeably higher than the target amount, 3) rich and famous companies have crowdfunded projects²⁶, 4) firms that develop riskier products that involve sufficiently high investment costs and have high demand uncertainty, e.g. technology gadgets, appear to seek reward-based crowdfunding most often. We also predict that firms offer products at par or at a discount rather than premium during crowdfunding campaigns. These features are specific to our model and would enable to test our predictions relative to alternative papers.

We argue that reward-based crowdfunding is complementary to more traditional sources of external financing, e.g., angel or venture capital investors could offer financing conditional on a successful crowdfunding campaign. This is indeed what happened to Pebble, which was turned down by many venture capitalists before its first Kickstarter campaign, but raised \$15M in venture capital from CRV after the campaign.²⁷ There can also be more subtle interactions between financing needs and reward-based crowdfunding, e.g., the public nature of crowdfunding is likely to mitigate asymmetric information problems between firms and investors. These

²⁶The Economist, 2013, "Is it unfair for famous people to use Kickstarter?", May 14, <http://www.economist.com/blogs/economist-explains/2013/05/>

²⁷Liz Gannes, 2013, "Now Fully Kickstartered, Pebble Raises \$15M in Venture Capital From CRV", May 16, <http://allthingsd.com/20130516/now-fully-kickstartered-pebble-raises-15m-in-venture-capital-from-crv/>

interactions would be an interesting avenue for future research.

A Appendix

A.1 Introductory lemmas

Lemma 7 For any $c \in \{0, 1, \dots, M\}$, $\mathbb{E}[m|m \geq c]$ is decreasing in c .

Proof. Since c is an integer, it is sufficient to show that for any $c \in \{0, 1, \dots, M\}$ we have

$$\mathbb{E}[m|m \geq c+1] > \mathbb{E}[m|m \geq c],$$

which can be expressed as

$$\frac{\sum_{m=c+1}^M m q_m}{\sum_{m=c+1}^M q_m} > \frac{\sum_{m=c}^M m q_m}{\sum_{m=c}^M q_m} = \frac{c q_c + \sum_{m=c+1}^M m q_m}{q_c + \sum_{m=c+1}^M q_m}$$

Simplifying, we obtain

$$q_c \sum_{m=c+1}^M m q_m > c q_c \sum_{m=c+1}^M q_m \Leftrightarrow q_c \sum_{m=c+1}^M (m - c) q_m > 0,$$

where the inequality holds because $m - c > 0$ for any $c + 1 \leq m \leq M$ and with a beta-binomial distribution, $q_m > 0$ for any m . ■

Lemma 8 For any $c \in \{0, 1, \dots, M\}$, $\Pr(m \geq c) \mathbb{E}[D(m) | m \geq c]$ is monotonically increasing (decreasing) in c for any $c < (>) \tilde{m}$; $\Pr(m \geq c) \mathbb{E}[D(m) | m \geq c]$ is maximized when $c = \tilde{m}$, where $\tilde{m}$ is given by (6).

Proof. As c is an integer, consider the difference

$$\begin{aligned} & \Pr(m \geq c+1) \mathbb{E}[D(m) | m \geq c+1] - \Pr(m \geq c) \mathbb{E}[D(m) | m \geq c] \\ &= \sum_{m=c+1}^M D(m) q_m - \sum_{m=c}^M D(m) q_m = -D(c) q_c. \end{aligned}$$

Since $q_c > 0$ for any c , the difference has the same sign as $-D(c) q_c$. From (6) and (7), we obtain

$$\begin{aligned} D(c) &< 0 \text{ if } c < \tilde{m} \\ D(c) &\geq 0 \text{ if } c = \tilde{m}, \\ D(c) &> 0 \text{ if } c > \tilde{m} \end{aligned}$$

which implies that $\Pr(m \geq c) \mathbb{E}[D(m) | m \geq c]$ is indeed monotonically increasing (decreasing) in c for any $c < (>) \tilde{m}$. This also implies that $\Pr(m \geq c) \mathbb{E}[D(m) | m \geq c]$ is maximized when $c = \tilde{m}$. ■

A.2 Proof of Proposition 2

We only need to consider $I_0 < I < I_0 + \delta M \frac{\lambda+N}{\lambda+M}$, as the value of learning is zero otherwise. From (6), it is clear that $\tilde{m}$ is weakly increasing in I . Consider $I < \delta N \theta_0$. From (7) and (10), the expected value of learning is

$$\begin{aligned} U^I &= -\delta \mathbb{E}[D(m) | m < \tilde{m}] \Pr(m < \tilde{m}) = -\delta \sum_{m=0}^{\tilde{m}-1} D(m) q_m \\ &= \delta \sum_{m=0}^{\tilde{m}-1} \left(I - \delta \frac{\lambda+N}{\lambda+M} m + I_0 \right) q_m. \end{aligned}$$

Since $-D(m) = (I - \delta \frac{\lambda+N}{\lambda+M} m - I_0)$ is positive and increasing in I for any $m < \tilde{m}$ and $I < \delta N \theta_0$, and since $\tilde{m}$ is weakly increasing in I , we obtain that U^I is increasing in I .

Consider $I > \delta N \theta_0$. From (7) and (11), the expected value of learning is

$$\begin{aligned} U^{NI} &= \delta \mathbb{E}[D(m) | m \geq \tilde{m}] \Pr(m \geq \tilde{m}) = \delta \sum_{m=\tilde{m}}^M D(m) q_m \\ &= \delta \sum_{m=\tilde{m}}^M \left(\delta \frac{\lambda+N}{\lambda+M} m + I_0 - I \right) q_m. \end{aligned}$$

Since $D(m) = (\delta \frac{\lambda+N}{\lambda+M} m + I_0 - I)$ is positive and decreasing in I for any $m \geq \tilde{m}$ and $I > \delta N \theta_0$ and since $\tilde{m}$ is weakly increasing in I , U^{NI} is decreasing in I . This implies that $I = \delta N \theta_0$ maximizes the expected value of learning.

A.3 Proof of Proposition 3

For the sake of exposition, we have limited indexing the variables of interest in the main text and only highlighted the dependence on m . For this proof it is necessary to consider the dependence on λ . We denote

$$\begin{aligned} q_m(\lambda) &= \binom{M}{m} \frac{B(\lambda \theta_0 + m, \lambda(1 - \theta_0) + M - m)}{B(\lambda \theta_0, \lambda(1 - \theta_0))} \\ \tilde{m}(\lambda) &= \left\lceil \frac{\lambda + M}{\lambda + N} \left(\frac{I - I_0(\lambda)}{\delta} \right) \right\rceil \\ D(m, \lambda) &= \frac{\lambda + N}{\lambda + M} \delta m + I_0(\lambda) - I, \end{aligned} \tag{27}$$

where $I_0(\lambda) = \delta \frac{\lambda \theta_0 (N-M)}{\lambda+M}$. The equations in (27) are identical to (4), (6) and (7) respectively. We also denote the cumulative distribution of m

$$Q_m(\lambda) = \sum_{k=0}^m q_k(\lambda).$$

Since the distribution of m is beta-binomial, for any pair $\lambda \in \{\lambda_1, \lambda_2\}$ such that $\lambda_2 > \lambda_1$, the distribution with higher λ_2 second order stochastically dominates (SOSD) the one with λ_1 , i.e.,

$$\sum_{k=0}^m Q_k(\lambda_2) \leq \sum_{k=0}^m Q_k(\lambda_1) \quad (28)$$

for all $m = \{0, 1, \dots, M\}$; the inequality is strict for $m < M - 1$.²⁸

From (10) and (11), we obtain

$$\begin{aligned} U^I(\lambda) &= -\delta \sum_{m=0}^{\tilde{m}(\lambda)-1} D(m, \lambda) q_m(\lambda) \text{ for } I < \delta N \theta_0 \\ U^{NI}(\lambda) &= \delta^2 \left(N \theta_0 - \frac{I}{\delta} \right) - \delta \sum_{m=0}^{\tilde{m}(\lambda)-1} D(m, \lambda) q_m(\lambda) \text{ for } I \geq \delta N \theta_0 \end{aligned} \quad (29)$$

From Abel's Lemma²⁹, and $D(m+1, \lambda) - D(m, \lambda) = \delta \frac{\lambda+N}{\lambda+M}$,

$$\delta \sum_{m=0}^{\tilde{m}(\lambda)-1} D(m, \lambda) q_m(\lambda) = \delta D(\tilde{m}(\lambda), \lambda) - \delta^2 \frac{\lambda+N}{\lambda+M} \sum_{m=0}^{\tilde{m}(\lambda)-1} Q_m(\lambda) \quad (30)$$

We can express the investment threshold as

$$\tilde{m}(\lambda) = \frac{\lambda+M}{\lambda+N} \left(\frac{I - I_0(\lambda)}{\delta} \right) + \varepsilon(\lambda), \quad (31)$$

where $0 \leq \varepsilon(\lambda) < 1$ is the rounding error. Using (27) and (31) we obtain

$$D(\tilde{m}(\lambda), \lambda) = \frac{\lambda+N}{\lambda+M} \delta \tilde{m}(\lambda) + I_0(\lambda) - I = \delta \frac{\lambda+N}{\lambda+M} \varepsilon(\lambda) \quad (32)$$

Replacing (30) and (32) in (29), we express the firm's expected value of learning as

$$U^I(\lambda) = \delta^2 \frac{\lambda+N}{\lambda+M} \left(\varepsilon(\lambda) \sum_{m=0}^{\tilde{m}(\lambda)-2} Q_m(\lambda) + (1 - \varepsilon(\lambda)) \sum_{m=0}^{\tilde{m}(\lambda)-1} Q_m(\lambda) \right), \quad (33)$$

$$U^{NI}(\lambda) = (\delta^2 N \theta_0 - \delta I) + \delta^2 \frac{\lambda+N}{\lambda+M} \left(\varepsilon(\lambda) \sum_{m=0}^{\tilde{m}(\lambda)-2} Q_m(\lambda) + (1 - \varepsilon(\lambda)) \sum_{m=0}^{\tilde{m}(\lambda)-1} Q_m(\lambda) \right). \quad (34)$$

From (27), we obtain

$$\begin{aligned} \tilde{m}(\lambda_2) &\leq \tilde{m}(\lambda_1) \text{ if } I < N \delta \theta_0 \\ \tilde{m}(\lambda_2) &\geq \tilde{m}(\lambda_1) \text{ if } I > N \delta \theta_0, \end{aligned}$$

²⁸This can be proved analytically from the fact that beta-binomial distributions have a unimodal likelihood ratio, which implies second order stochastic dominance. See Hopkins, Kornienko, 2003 for the proof of continuous distributions, the proof for discrete distributions is available upon request.

²⁹ $\sum_{i=0}^N a_i b_i = A_N b_N - \sum_{i=0}^{N-1} A_i b_i$, where $A_n = \sum_{i=0}^n a_i$.

If $I = N\delta\theta_0$, then $\tilde{m}(\lambda_2) = \tilde{m}(\lambda_1) = \lceil \frac{I}{\delta} \rceil$ is independent of λ . Since the effect of λ on the firms that would break even without learning is different from its effect on the firms that would not, we analyze these two cases separately.

Case 1: firms with $I < N\delta\theta_0$

In this case, we have $\tilde{m}(\lambda_2) \leq \tilde{m}(\lambda_1)$. We denote $\Delta\tilde{m} = -(\tilde{m}(\lambda_2) - \tilde{m}(\lambda_1))$, where $\Delta\tilde{m} = \{0, 1, \dots\}$. From (31), we obtain

$$\varepsilon(\lambda_2) = \varepsilon(\lambda_1) - \Delta\tilde{m} + \frac{(\lambda_2 - \lambda_1)(N - M)}{(\lambda_2 + N)(\lambda_1 + N)} \left(N\theta_0 - \frac{I}{\delta} \right)$$

This and (33) enable us to decompose the effect of an increase in λ as

$$\begin{aligned} U^I(\lambda_2) - U^I(\lambda_1) &= -\delta^2 \frac{\lambda_1 + N}{\lambda_1 + M} (G_1^I + G_2^I + G_3^I) \\ &\quad - \frac{(\lambda_2 - \lambda_1)(N - M)}{(\lambda_2 + N)(\lambda_1 + M)} (U^I(\lambda_2) + Q_{\tilde{m}(\lambda_2)-1}(\lambda_2) (\delta^2 N\theta_0 - \delta I)), \end{aligned} \quad (35)$$

where

$$\begin{aligned} G_1^I &\equiv \varepsilon(\lambda_1) \left(\sum_{m=0}^{\tilde{m}(\lambda_1)-2} Q_m(\lambda_1) - \sum_{m=0}^{\tilde{m}(\lambda_2)-2} Q_m(\lambda_2) \right), \\ G_2^I &\equiv (1 - \varepsilon(\lambda_1)) \left(\sum_{m=0}^{\tilde{m}(\lambda_1)-1} Q_m(\lambda_1) - \sum_{m=0}^{\tilde{m}(\lambda_2)-1} Q_m(\lambda_2) \right), \\ G_3^I &\equiv -\Delta\tilde{m} Q_{\tilde{m}(\lambda_2)-1}(\lambda_2). \end{aligned}$$

The second term in (35) is non-positive and it is strictly negative if $N < M$, because $U^I(\lambda_2) > 0$ and $I < \delta N\theta_0$. The sign of the first term in (35) is determined by $G_1^I + G_2^I + G_3^I$.

If $\Delta\tilde{m} = 0$, i.e., $\tilde{m}(\lambda_1) = \tilde{m}(\lambda_2)$, then $G_1^I + G_2^I + G_3^I \geq 0$ follows from $G_3 = 0$, and $G_1^I, G_2^I \geq 0$ due to second order stochastic dominance (28).

If $\Delta\tilde{m} > 0$, then we can further decompose

$$\begin{aligned} G_1^I + G_2^I + G_3^I &= \varepsilon(\lambda_1) \left(\sum_{m=0}^{\tilde{m}(\lambda_1)-2} Q_m(\lambda_1) - \sum_{m=0}^{\tilde{m}(\lambda_1)-2} Q_m(\lambda_2) \right) \\ &\quad + (1 - \varepsilon(\lambda_1)) \left(\sum_{m=0}^{\tilde{m}(\lambda_1)-1} Q_m(\lambda_1) - \sum_{m=0}^{\tilde{m}(\lambda_1)-1} Q_m(\lambda_2) \right) \\ &\quad + \sum_{m=\tilde{m}(\lambda_2)-1}^{\tilde{m}(\lambda_2)+\Delta\tilde{m}-2} (Q_m(\lambda_2) - Q_{\tilde{m}(\lambda_2)-1}(\lambda_2)) \\ &\quad + (1 - \varepsilon(\lambda_1)) (Q_{\tilde{m}(\lambda_2)+\Delta\tilde{m}-1}(\lambda_2) - Q_{\tilde{m}(\lambda_2)-1}(\lambda_2)), \end{aligned}$$

which is non-negative for any $\Delta\tilde{m} > 0$, because of second order stochastic dominance (28) and because the cumulative probability is increasing in m . Hence the value of learning decreases with λ for all firms with $I < N\delta\theta_0$.

Case 2: firms with $I \geq N\delta\theta_0$

In this case, we have $\tilde{m}(\lambda_2) \geq \tilde{m}(\lambda_1)$. We again denote $\Delta\tilde{m} = \tilde{m}(\lambda_2) - \tilde{m}(\lambda_1)$, where $\Delta\tilde{m} = \{0, 1, \dots\}$ and from (31) we obtain the following relationship between $\varepsilon(\lambda_1)$ and $\varepsilon(\lambda_2)$:

$$\varepsilon(\lambda_1) = \varepsilon(\lambda_2) - \Delta\tilde{m} + \frac{(\lambda_2 - \lambda_1)(N - M)(I - N\delta\theta_0)}{\delta(\lambda_2 + N)(\lambda_1 + N)}. \quad (36)$$

The above and (33) enable us to decompose again the effect of an increase in λ as

$$\begin{aligned} U^{NI}(\lambda_2) - U^{NI}(\lambda_1) &= -\delta^2 \frac{\lambda_1 + N}{\lambda_1 + M} (G_1^{NI} + G_2^{NI} + G_3^{NI}) \\ &\quad - \frac{(\lambda_2 - \lambda_1)(N - M)}{(\lambda_2 + N)(\lambda_1 + M)} (U^{NI}(\lambda_2) + \delta(I - \delta N\theta_0)(1 - Q_{\tilde{m}(\lambda_1)-1}(\lambda_1))), \end{aligned} \quad (37)$$

where

$$\begin{aligned} G_1^{NI} &\equiv \varepsilon(\lambda_2) \left(\sum_{m=0}^{\tilde{m}(\lambda_2)-2} Q_m(\lambda_2) - \sum_{m=0}^{\tilde{m}(\lambda_1)-2} Q_m(\lambda_1) \right), \\ G_2^{NI} &\equiv (1 - \varepsilon(\lambda_2)) \left(\sum_{m=0}^{\tilde{m}(\lambda_2)-1} Q_m(\lambda_2) - \sum_{m=0}^{\tilde{m}(\lambda_1)-1} Q_m(\lambda_1) \right), \\ G_3^{NI} &\equiv -\Delta\tilde{m} Q_{\tilde{m}(\lambda_1)-1}(\lambda_1). \end{aligned}$$

It is clear that the second term of (37) is non-positive and it is strictly negative if $N < M$, because $U^{NI}(\lambda_2) > 0$, and $I \geq N\delta\theta_0$. As in case 1, it is easy to see that if $\Delta\tilde{m} = 0$, then $\tilde{m}(\lambda_1) = \tilde{m}(\lambda_2)$ and $G_1^{NI} + G_2^{NI} + G_3^{NI} \geq 0$. If $\Delta\tilde{m} > 0$, then we can follow the same derivation as before to prove that $G_1^{NI} + G_2^{NI} + G_3^{NI} \geq 0$ (keeping in mind that now $\tilde{m}(\lambda_2) > \tilde{m}(\lambda_1)$).

This proves that value of learning is higher if there is more uncertainty, i.e., lower λ .

A.4 Proof of Proposition 4

The firm's investment decisions are characterized by (17) and (18) for states $S = Y$ and $S = N$. We aim to find the target $\bar{m}'$, that maximizes firms expected profit. Because consumers observe each other's decisions, they coordinate to back the firm only if the $m \geq \bar{m}_{YA}$. The firm does not benefit from setting a target below the investment threshold, which implies that

$$\bar{m}' \geq \bar{m}_{YA}. \quad (38)$$

From (18), we have $\tilde{m} \leq \bar{m}_{NA}$. The ordering between $\tilde{m}$, $\bar{m}_{YA}$, $\bar{m}_{NA}$ depends on parameters χ_Y and χ_N . We have the following possibilities: 1) $\tilde{m} \leq \bar{m}_{NA} \leq \bar{m}_{YA}$; 2) $\tilde{m} \leq \bar{m}_{YA} \leq \bar{m}_{NA}$; 3) $\bar{m}_{YA} \leq \tilde{m} \leq \bar{m}_{NA}$, and need to analyze each of these cases separately.

Case 1: $\tilde{m} \leq \bar{m}_{NA} \leq \bar{m}_{YA}$

From (17) and (38), the firm always invests if it meets target $\bar{m}'$. However, it also has incentives to invest provided that $m \geq \bar{m}_{NA}$ if it does not meet the target. Given the payoff structure in Section 4.1, platform's break even condition (12), the expected firm value at date 0 is

$$\mathbb{E}[\pi_0] = \delta \Pr(m \geq \bar{m}_{NA}) \mathbb{E}[D(m) | m \geq \bar{m}_{NA}] - \delta \Pr(\bar{m}_{NA} \leq m < \bar{m}') \chi_N - Z \quad (39)$$

The only term that depends on the announced target is the expected reputation cost, $\Pr(\bar{m}_{NA} \leq m < \bar{m}') \chi_N \geq 0$. In order to minimize this cost, it is optimal for the firm to set $\bar{m}'$ as low as possible. Given the constraint (38), the firm optimally sets $\bar{m}' = \bar{m}_A^* = \bar{m}_{YA}$. Because $\bar{m}_{NA} \leq \bar{m}_{YA}$, the firm also invests in state $S = Y$, provided that (18) holds.

Case 2: $\tilde{m} \leq \bar{m}_{YA} \leq \bar{m}_{NA}$

Given (38), there are two possibilities: $\bar{m}' \geq \bar{m}_{NA}$ or $\bar{m}_{YA} \leq \bar{m}' \leq \bar{m}_{NA}$. If $\bar{m}' \geq \bar{m}_{NA}$, as in case 1, the expected profit is given by (39). Conditional on $\bar{m}' \geq \bar{m}_{NA}$, the firm sets $\bar{m}' = \bar{m}_{NA}$. If $\bar{m}_{YA} \leq \bar{m}' \leq \bar{m}_{NA}$, the expected payoff to the firm is

$$\mathbb{E}[\pi_0] = \delta \Pr(m \geq \bar{m}') \mathbb{E}[D(m) | m \geq \bar{m}'] - Z.$$

Since $\bar{m}' \geq \tilde{m}$ and from Lemma 8, note that $\Pr(m \geq \bar{m}') \mathbb{E}[D(m) | m \geq \bar{m}']$ is monotonically decreasing in $\bar{m}'$, and it is optimal to set the target as low as possible. Given (38), the firm sets $\bar{m}' = \bar{m}_{YA}$ conditional on $\bar{m}_{YA} \leq \bar{m}' \leq \bar{m}_{NA}$. Since $\bar{m}_{YA} \leq \bar{m}_{NA}$, we can conclude that the equilibrium target is $\bar{m}' = \bar{m}_A^* = \bar{m}_{YA}$ and the firm does not invest in state $S = N$.

Case 3: $\bar{m}_{YA} \leq \tilde{m} \leq \bar{m}_{NA}$

If $\bar{m}' \geq \bar{m}_{NA}$, then the expected profit is given by (39) and the firm sets the target to $\bar{m}' = \bar{m}_{NA}$. If $\bar{m}_{YA} \leq \bar{m}' \leq \bar{m}_{NA}$, then the expected payoff to the firm is

$$\mathbb{E}[\pi_0] = \delta \Pr(m \geq \bar{m}') \mathbb{E}[D(m) | m \geq \bar{m}'] - Z.$$

From Lemma 8, the first term is maximized at $\bar{m}' = \tilde{m}$, and therefore the firm sets $\bar{m}' = \bar{m}_A^* = \tilde{m}$.

Thresholds

From (6) and (17), we obtain that $\bar{m}_{YA} \geq (\leq) \tilde{m}$ if

$$\chi_Y \leq (\geq) \frac{\lambda + M}{\lambda + N} (I - I_0)$$

In addition, from (17) and (18), we obtain that $\bar{m}_{YA} \geq (\leq) \bar{m}_{NA}$ if

$$\chi_Y + \frac{N - M}{\lambda + N} \chi_N \leq (\geq) \frac{\lambda + M}{\lambda + N} (I - I_0).$$

Combining these results, we obtain Proposition 4.

A.5 Proof of Proposition 5

The firm only obtains funds if consumers expect it to actually invest at date 1. That is, whether or not the firm meets the target, it will obtain funds if

$$m \geq \bar{m}_K.$$

The firm's choice over the target alters only its expected reputation costs. Suppose that the firm announces a target $\bar{m}' \geq \bar{m}_K$. From the table in Section 4.2 and the platform's break even condition (12), the payoff to the firm is

$$\mathbb{E}[\pi_0] = \delta \Pr(m \geq \bar{m}_K) \mathbb{E}[D(m) | m \geq \bar{m}_K] + \delta \Pr(\bar{m}_K \leq m < \bar{m}') \chi_N - Z.$$

In order to minimize expected reputation costs, the firm could set the target to $\bar{m}' = \bar{m}_K$. However, the firm could also set a lower target. Suppose that it sets $\bar{m}' \leq \bar{m}_K$. Using again the platform's break even condition (12), this implies that the payoff to the firm is

$$\delta \Pr(m \geq \bar{m}_K) \mathbb{E}[D(m) | m \geq \bar{m}_K] - \delta Z.$$

As the result the firm's best response is to set any target $\bar{m}' \leq \bar{m}_K$.

A.6 Proof of Proposition 6

This follows from Part 1 in Proposition 4, (38), and law of total expectations. We also account for the fact that the opportunity cost for a firm with $I \leq \delta N \theta_0$ (resp. $I > \delta N \theta_0$) is $\mathbb{E}[D(m)] = \delta N \theta_0 - I$ (resp. 0). The last statement follows directly from (18)

A.7 Distribution of the ratio of pledges to target

The figures below are based on data from Kickstarter. The upper figure, which plots $\Pr\left(\frac{pm}{pm} \leq x \mid \frac{pm}{pm} \geq 1\right)$, is constructed using all 2015 Technology and Theatre projects completed from January 1, 2015 to September 17, 2015. We then constructed the unconditional distribution, $\Pr\left(\frac{pm}{pm} \leq x\right)$, thanks to the summary statistics available on Kickstarter on September 17, 2015. This statistics cover the full history of Kickstarter, so we assume that the 2015 data is statistically similar to earlier data. We use $\Pr\left(\frac{pm}{pm} \geq 1\right)$ reported on the site, which is 0.2018 for Technology category and 0.6089 for Theatre, and the frequency of unsuccessful projects raising 0%, 1 – 20%, ..., 81 – 99% in these categories. We then use the law of total expectations to find $\Pr\left(\frac{pm}{pm} \leq x\right)$.

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B For Online Publication

B.1 Pre-selling with pre-commitment

We modify the setting of Figure 1 as follows. While a frictionless consumer survey remains unrealistic, we assume here that instead of pre-selling a product through a third-party platform, the firm can choose whether or not to crowdfund its project, and commits to the main features of its own pre-selling scheme at date 0 in the morning. As before, provided the firm decides to pre-sell its product, it sets p_0 at date 0 at mid-day, and a sample of M consumers decide whether to pre-order the product at date 0 in the afternoon. At date 0 in the evening, the firm receives funds, if any, and the rest of the game proceeds as before. In this section, we also prove formally some statements made in Section 4.

In Section 3, we established that there is no value of learning for firms with $I \leq I_0$. Firms with $I \leq I_0$ always invest at date 1 and can therefore credibly commit to deliver the product regardless of the pre-selling scheme. However, these firms have nothing to gain from pre-selling future products be it directly or through third party platforms. In what follows, we focus on the case where $I > I_0$.

B.1.1 Full money-back guarantees

The first contractual feature the firm could commit to is a money-back guarantee that fully insures the consumers who pre-ordered the product at date 0 against a decision to not invest at date 1.

Proposition 9 *Pre-selling with a full money-back guarantee achieves the first-best as a subgame-perfect Nash equilibrium (SPNE). In such SPNE, $p_0 = \delta^2$, $p_2 = 1$, and all 1-consumers in sample M pre-order the product.*

Proof. We derive SPNE by backward induction. At date 2, only 1-consumers are willing to buy the product at the positive price, and they buy it at any $p_2 \leq 1$. Because the firm's profit at date 2 is increasing in p_2 , the firm sets $p_2 = 1$. At date 1, provided that $m \leq M$ consumers pre-ordered the product, the firm's expected profit is $(\frac{p_0}{\delta^2} - 1)m + D(m)$ if it invests, where $D(m)$ is defined in (7). It obtains zero if it does not invest. Consumers are fully insured against no investment. Therefore, they pre-order the product if, and only if, $p_0 \leq \delta^2$, i.e., whenever the price compensates them for the time value of money. As the firm's expected profit at date 0 is increasing in p_0 , the firm optimally sets $p_0 = \delta^2$. As 0-consumers do not pre-order the product

at $p_0 = \delta^2 > 0$, the firm credibly learns about demand at date 1. Further, the firm's investment decision remains identical to the first best described in Proposition 1 and all payoffs are the same as under the first best outcome. ■

Proposition 4 highlights that pre-selling the product with a full-money back guarantee is an efficient mechanism to learn about demand and leads to the first best. Yet, it requires firms to be able to, and to choose to, pre-commit to such guarantees. While travel agencies, governed by regulation, and large, well known corporations such as Apple and Sony, which offer pre-ordering possibility for many products through iTunes and Playstation, are likely to be able to credibly commit to such guarantees, smaller, innovative companies are likely unable to do so.

B.1.2 Limited money-back guarantees and the value of transparency

Whenever the firm cannot commit to a full-money back guarantee, the consumers who pre-ordered the product need to form beliefs about the actions from other consumers, as it determines the probability with which they will receive the product at date 2. We consider two main contractual features that the firm can commit to at date 0 in the morning: a limited money-back guarantee and transparency. A limited money-back guarantee implies that the firm can pre-commit to return consumers a fraction $1 - \kappa$ of the funds that they contributed at date 0 if the firm does not invest at date 1, where $\kappa \in [\bar{\kappa}, 1]$, with $\bar{\kappa} > 0$. The purpose of the money-back guarantee is similar to that of the reputation cost of no-delivery in Section 3.

The transparency choice is as follows. We denote $\tau \in \{OP, TR\}$ the choice of the information that is available to backers about other backer pledges at date 0. When the firm commits to transparency, $\tau = TR$, consumers play a simultaneous move game with perfect information. When $\tau = OP$, consumers play a simultaneous move game with imperfect information. That is, they cannot observe the decisions made by other backers, and they decide simultaneously whether or not to pre-order the product at date 0. Hence, each consumer needs to form beliefs about other consumer preferences and participation decisions based on his own valuation for the product and the distribution of other valuations.

We proceed by backward induction, and as before, at date 2, it is optimal for the firm to capture all consumer surplus by setting $p_2 = 1$. At date 1, suppose that all 1-consumers in sample M pre-ordered the product at date 0.³⁰ Since the firm

³⁰For simplicity, we restrict our attention to pure strategies. If customers with a high valuation do not buy the product, then there is no learning and the expected value remains to the initial value with initial beliefs. If pre-selling is possible, such potential (uninteresting) equilibrium would

raised $p_0 m$ at date 0, the firm invests if, and only if,

$$\mathbb{E}[\pi_1|m] = \frac{p_0}{\delta} m + \delta(N - M) \mathbb{E}[\theta|m] - I \geq \kappa \frac{p_0}{\delta} m. \quad (40)$$

From (3), we obtain that the firm invests at date 1 if, and only if,

$$m \geq \bar{m} = \max \left(\left[\left(\frac{(N - M)}{\lambda + M} + (1 - \kappa) \frac{p_0}{\delta^2} \right)^{-1} \left(\frac{I - I_0}{\delta} \right) \right], 0 \right). \quad (41)$$

If the firm invests, its expected value at date 1 is

$$\mathbb{E}[\pi_1|m] = -I + \delta(N - M) \frac{\lambda \theta_0 + m}{\lambda + M} + \frac{p_0}{\delta} m. \quad (42)$$

We then turn to the backer's decision to pre-order the product at date 0. Since 0-consumers do not buy the product, we focus on the decisions made by 1-consumers under both transparency and opacity. As consumers are forward looking and rational, they correctly anticipate the firm's investment decision at date 1. We can characterize consumer best responses for any $I > I_0$ as follows.

Lemma 10 (1) If $\tau = TR$, all 1-consumers pre-order the product if, and only if $p_0 \leq \delta^2$ and $m \geq \bar{m}$. (2) If $\tau = OP$, all 1-consumers pre-order the product if, and only if

$$p_0 \leq \delta^2 \frac{\Pr(m \geq \bar{m} | m \geq 1)}{\kappa + (1 - \kappa) \Pr(m \geq \bar{m} | m \geq 1)} \quad (43)$$

Proof. See Appendix B.2. ■

Lemma 10 shows that if information about other backer preferences and decisions is public, backers can coordinate and back the project only to firms that have incentives to invest. Coordination also ensures that there is no uncertainty about the firm's decision, and if the firm meets the target $\bar{m}$, all 1-consumers pre-order the product as long as the price compensates for discounting. Hence, with $\tau = TR$, the funds raised at date 0 are $p_0 m$ if $m \geq \bar{m}$ and $p_0 \leq \delta^2$, and zero otherwise. Because reward-based crowdfunding implies $\tau = TR$, this also proves our earlier claims about backer behaviour in Section 4.

With $\tau = OP$, backers cannot coordinate. Hence, when they decide whether or not to pre-order the product, they need to form beliefs about the probability that the firm will invest and that they will receive the product. When $\kappa > 0$, the backers need to be compensated for the risk that the firm may not deliver the product and generally require a larger discount.

also be eliminated if we assume that consumers have lexicographic preferences.

Finally, from (40), $\mathbb{E}[\pi_1|m]$ increases with p_0 , and hence so does date 1's expected profit. Therefore, the firm sets $p_0 = \delta^2$ if $\tau = TR$, and (43) if $\tau = OP$. When choosing τ at date 0, the firm faces a trade-off between the benefit of keeping some of the funds raised if it chooses to not invest and the discount it needs to offer to at date 0 to induce rational backers to participate.

Proposition 11 *For any κ , the firm is weakly better off under transparency. Therefore, $\tau = TR$ is always an optimal equilibrium strategy for the firm.*³¹

Proof. See Appendix B.3. ■

Proposition 11 shows that the firm chooses transparency over opacity at any given κ . The intuition is as follows. Suppose that the firm has the same investment threshold under $\tau = TR$ and $\tau = OP$. Then the discount the firm needs to offer under $\tau = OP$ is sufficiently large to compensate for any benefit of keeping funds in the case where the number of consumers who pre-order the product is low. In addition, as we show, the optimal investment threshold at date 1 is weakly higher under $\tau = OP$ than under $\tau = TR$, which provides the firm with another benefit of choosing $\tau = TR$.

We now turn to the optimal full-commitment scheme.

Proposition 12 *The firm optimally sets $\tau = TR$ and chooses the maximum level of money-back guarantee, i.e., $\kappa = \bar{\kappa}$.*

Proof. From Proposition 11 $\tau = TR$ (weakly) dominates $\tau = OP$. Appendix A.4. proves that the investment threshold ($\bar{m}_{TR} \geq \tilde{m}$) under $\tau = TR$ (weakly) increases with κ and that the firm's expected profit at date 0 is $\Pr(m \geq \bar{m}_{TR}) \mathbb{E}[D(m) | m \geq \bar{m}_{TR}]$, which from Lemma 8 in Appendix A.1 is maximized at $\bar{m}_{TR} = \tilde{m}$ and decreases with $\bar{m}_{TR}$ for any $\bar{m}_{TR} \geq \tilde{m}$. ■

Proposition 12 shows that the firm that can pre-commit chooses transparency and the highest level of money-back guarantee, i.e., the lowest κ , that it can commit to. Since transparency dominates opacity for any κ , backers only back firms that they expect will have sufficient incentives to invest. The threshold for investment must be lower than the first best threshold $\tilde{m}$ defined in (6) and it decreases with κ . As the expected firm payoff from pre-selling the product decreases with the threshold, the firm benefits from committing to the highest feasible level of money-back guarantee.

³¹While Proposition 11 establishes that the firm is weakly better off, this statement is largely due the potential effect of rounding as $\bar{m}$ must be an integer. In most cases, the firm is strictly worse off if it choosing $\tau = OP$ instead of $\tau = TR$.

We obtain the following result for the opposite limit:

Corollary 13 *If the firm cannot commit to any money-back guarantee, i.e., $\bar{\kappa} = 1$, pre-selling the product to all potential consumers is not incentive compatible even though $\tau = TR$.*

Proof. Setting $\kappa = \bar{\kappa} = 1$ in (41), the firm invests if, and only if, $m \geq \bar{m} = \left\lceil \frac{\delta(\lambda+M)}{N-M} (I - I_0) \right\rceil$. If $M \rightarrow N$, then $\bar{m} \rightarrow \infty$. ■

This echoes the earlier result that it is impossible to pre-sell the product to all potential consumers if the reputation cost of no-delivery is low. This is because this reputation cost and the money-back guarantee serve exactly the same role.

B.2 Proof of Lemma 10

For a 1-consumer, the opportunity cost of waiting is zero, either because there is no product or because the firm extracts all consumer surplus at date 2 by setting $p_2 = 1$.

Consider $\tau = TR$. Consumer i observes the number of other consumers who pre-order the product, m_{-i} . If $m_{-i} \geq \bar{m} - 1$, then if a 1-consumer backs the project at date 0, the firm will invest at date 1 with probability 1 and the consumer's utility from pre-ordering the product is $\delta^2 \cdot 1 - p_0$. Hence he participates as long as $\delta^2 - p_0 \geq 0$. Further, the condition $m_{-i} \geq \bar{m} - 1$ is equivalent to $m = m_{-i} + 1 \geq \bar{m}$. If $m_{-i} < \bar{m} - 1$, then the firm will not invest with probability 1 and consumer i may be unable to buy the product at date 2. The utility from pre-ordering the product is $-p_0 + (1 - \kappa)p_0 = -\kappa p_0 < 0$ for any $\kappa > 0$.

Consider now $\tau = OP$. Then 1-consumer i knows the distribution of m and the impact of his decision on m . Then, the firm will invest with probability $\Pr(m \geq \bar{m} | m \geq 1)$ (resp. $\Pr(m \geq \bar{m} | m \leq M - 1)$) if he participates (resp. does not participate). Hence, 1-consumers make identical decisions to back the project, if, and only if

$$\Pr(m \geq \bar{m} | m \geq 1) (\delta^2 - p_0) - \Pr(m < \bar{m} | m \geq 1) \kappa p_0 \geq 0,$$

which simplifies to (43).

B.3 Proof of Proposition 11

The firm sets p_0 as high as possible subject to 1-consumer's participation constraint (10). We denote $\bar{m}_\tau$ the investment threshold under τ and $\mathbb{E}[\pi_{0,\tau}](\kappa)$ the corresponding date 0 expected firm value.

From (41) and (42), when $\tau \in TR$, the firm optimally sets price $p_0 = \delta^2$ and it invests iff

$$m \geq \bar{m}_{TR}(\kappa) = \left\lceil \left(\frac{\lambda + N}{\lambda + M} - \kappa \right)^{-1} \left(\frac{I - I_0}{\delta} \right) \right\rceil. \quad (44)$$

Since the firm only obtains funds if, and only if, $m \geq \bar{m}_{TR}$, then

$$\mathbb{E}[\pi_{0,TR}](\kappa) = \Pr(m \geq \bar{m}_{TR}(\kappa)) \mathbb{E}[D(m) | m \geq \bar{m}_{TR}(\kappa)]. \quad (45)$$

With $\tau \in OP$, the firm sets the price to

$$p_0 = p_{0,OP} \equiv \delta^2 \frac{\Pr(m \geq \bar{m}_{OP}(\kappa) | m \geq 1)}{\kappa + (1 - \kappa) \Pr(m \geq \bar{m}_{OP}(\kappa) | m \geq 1)} \leq \delta^2, \quad (46)$$

and it invests if, and only if

$$m \geq \bar{m}_{OP}(\kappa) = \left\lceil \left(\frac{\lambda + N}{\lambda + M} - \kappa - (1 - \kappa) \left(1 - \frac{p_{0,OP}}{\delta^2} \right) \right)^{-1} \left(\frac{I - I_0}{\delta} \right) \right\rceil \quad (47)$$

Since the firm can obtain funds irrespectively of whether or not it invests, its expected date 0 profit is

$$\begin{aligned} \mathbb{E}[\pi_{0,OP}](\kappa) &= \Pr(m \geq \bar{m}_{OP}(\kappa)) (D(m) - (\delta^2 - p_{0,OP}) m | m \geq \bar{m}_{OP}(\kappa)) \\ &\quad + \kappa \Pr(m < \bar{m}_{OP}(\kappa)) p_{0,OP} \mathbb{E}[m | m < \bar{m}_{OP}(\kappa)] \end{aligned} \quad (48)$$

We proceed in two steps.

Step 1: Let us fix κ , with a corresponding $\bar{m}_{OP}(\kappa)$. From (44) and (47) there exists κ' such that

$$\kappa' = \kappa + (1 - \kappa) \left(1 - \frac{p_{0,OP}}{\delta^2} \right), \quad (49)$$

which implies

$$\bar{m}_{TR}(\kappa') = \bar{m}_{OP}(\kappa) \equiv \bar{c},$$

where $\bar{c} \in \{1, \dots, M\}$

Comparing ((45) and (48)) we obtain

$$\mathbb{E}[\pi_{0,TR}](\kappa') \geq \mathbb{E}[\pi_{0,OP}](\kappa),$$

if and only if

$$(\delta^2 - p_0) \Pr(m \geq \bar{c}) \mathbb{E}[m | m \geq \bar{c}] \geq \kappa \Pr(m < \bar{c}) p_0 \mathbb{E}[m | m < \bar{c}], \quad (50)$$

i.e., the loss from setting a lower price under $\tau = OP$ must be higher than the benefit of keeping the funds. From the law of total expectations and from (46), (50) simplifies to

$$\frac{\Pr(m \geq \bar{c}) \mathbb{E}[m|m \geq \bar{c}]}{\Pr(m \geq \bar{c}|m \geq 1)} \geq \mathbb{E}[m].$$

From Bayes' rule, we have $\Pr(m \geq \bar{c}|m \geq 1) = \frac{\Pr(m \geq \bar{c})}{\Pr(m \geq 1)}$. And from the law of total expectations

$$\mathbb{E}[m] = \Pr(m \geq 1) \mathbb{E}[m|m \geq 1] + \Pr(m = 0) \mathbb{E}[m|m = 0] = \Pr(m \geq 1) \mathbb{E}[m|m \geq 1].$$

Therefore the condition becomes

$$\mathbb{E}[m|m \geq \bar{c}] \geq \mathbb{E}[m|m \geq 1],$$

which holds for $\bar{c} = 1$, and holds for $\bar{c} > 1$ from Lemma 7 in Appendix A.1.

Step 2. Equation (49) implies that for any $\kappa, \kappa' \geq \kappa$. Hence, from (44) the investment threshold $\bar{m}_{TR}(\kappa)$ is non-increasing in κ ,

$$\bar{m}_{TR}(\kappa) \leq \bar{m}_{TR}(\kappa') = \bar{m}_{OP}(\kappa)$$

and $\bar{m}_{TR}(\kappa) \geq \tilde{m}$. From (45) and Lemma 7 in A.1, we have

$$\mathbb{E}[\pi_{0,TR}](\kappa) \geq \mathbb{E}[\pi_{0,TR}](\kappa') \geq \mathbb{E}[\pi_{0,OP}](\kappa),$$

which proves Proposition 11.