Quality Signaling through Crowdfunding Pricing

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Problem definition: This paper studies an entrepreneur's pricing strategy in a reward-based crowdfunding campaign under asymmetric product quality information. We propose two signaling mechanisms and investigate how entrepreneurs can leverage their pricing strategy to signal a high-quality project.

Academic/practical relevance: This problem is relevant to practice, as asymmetric quality information is a significant concern in reward-based crowdfunding. High-quality entrepreneurs seek credible mechanisms to signal the quality of projects to customers.

Methodology: We develop a stylized game-theoretic signaling model with funding and regular selling periods that captures asymmetric quality information between an entrepreneur and customers.

Results: We propose a new theory on quality signaling in crowdfunding. We show that contingent access to the regular selling market after running a successful crowdfunding campaign allows high-quality entrepreneurs to signal their quality through low funding prices (one-price signaling). A high-quality entrepreneur can increase his funding price and still signal his high-quality level if he commits to the future regular selling price (two-price signaling). We show that the distinct feature of crowdfunding, i.e., the probabilistic nature of crowdfunding, plays different roles in one- and two-price signaling. It is the driving force for the separating equilibrium in one-price signaling, and in two-price signaling, it affects how the entrepreneur should manipulate his funding and regular selling prices to reduce signaling cost.

Managerial implications: Entrepreneurs should be mindful of pricing in funding and regular selling periods because it could play an essential role in signaling quality information. Our findings suggest practical tools for quality signaling in crowdfunding. We also investigate when price commitment is the most beneficial for a high-quality entrepreneur, looking for potential signaling mechanisms.

Key words: reward-based crowdfunding; quality signaling; price commitment
History:

1. Introduction

Crowdfunding helps entrepreneurs get access to funds from individuals worldwide through the internet. It is increasingly being used as a mechanism to finance start-ups alongside classical financing methods such as venture capital and bank financing. The world market size for crowdfunding, which was estimated to be around USD 12.27 billion in 2019, is expected to reach USD 25.80 billion by the end of 2026 (QYResearch Report 2019). There are different forms of crowdfunding campaigns, such as reward-based, equity-based, debt-based, and donation-based campaigns. This paper focuses on the most widely practiced one, i.e., reward-based crowdfunding. Two of the most successful platforms running reward-based crowdfunding campaigns, Kickstarter and Indiegogo, have raised billions of dollars for entrepreneurs over the past decade[1].

In reward-based crowdfunding, an entrepreneur trying to fund his project starts a campaign on an online platform by introducing his project alongside the funding price and financing target level. Customers on crowdfunding platforms can back the campaign by pre-ordering and paying the funding price online. After a certain period of display on the platform (usually several weeks or months), the campaign will succeed if the funds collected during the campaign surpass the announced financing target level. Otherwise, the campaign fails, and the raised funds are returned to backers by the platform (on some platforms, such as Indiegogo, collected funds might not be returned to backers, even if the campaign fails). The funds raised in a successful campaign would be used to set up a business, such as hiring labor, buying materials, and producing the final product. A successful crowdfunding campaign has benefits beyond the immediate realized trade between entrepreneurs and project backers on crowdfunding platforms. Many buyers are unaware of the potentially attractive products offered on crowdfunding platforms; they only find out about a product once it hits the retail market. Thus, after running a successful campaign, entrepreneurs might consider continuing to sell to potential customers in the retail market after delivering pre-ordered products (Sayedi and Baghaie 2017, Kumar et al. 2020).[2]

In a crowdfunding campaign, customers decide whether to support the campaign based on their beliefs about product quality. While entrepreneurs know the true quality of their products, potential backers in the funding period can only form their beliefs about a product's quality based on the released information on crowdfunding platforms (e.g., online demos, pictures, and descriptions). In practice, many quality issues have been reported after pre-order customers receive their products and fundraisers fail to deliver what they promised to their backers (Tang 2016, Chakraborty and Swinney 2021). Given that customers' beliefs about a product's quality directly affect their decision to support a campaign, entrepreneurs must find ways to credibly signal their product quality (Kauffman

[1] https://www.kickstarter.com/help/stats

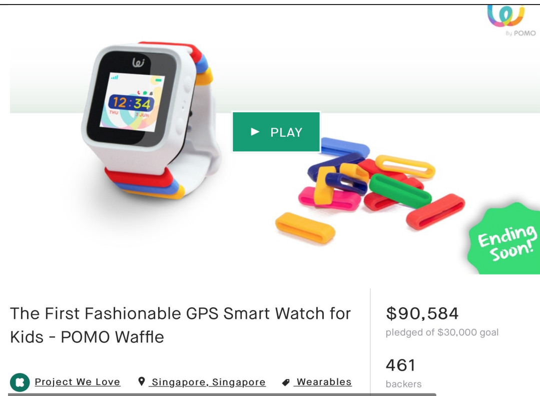
[2] Some entrepreneurs decide not to continue the business and simply pocket the profit of the funding period (Hu et al. 2015).

foundation 2016). Empirical studies have established that underlying project quality is associated with the success of crowdfunding efforts. These studies have shown that methods such as visual techniques have been successfully used to signal product quality to potential customers (Mollick 2014). However, such signaling methods may not be credible and are far from perfect. As Mollick (2014) stated "The nature of how entrepreneurs signal quality, legitimacy, and preparedness is much less defined in the virtual setting of crowdfunding than in traditional new venture settings, and future scholarship into this process may add to existing theory in this important area." Therefore, characterizing quality signaling tools can help high-quality entrepreneurs in desperate need of cash increase their chances of financing their projects.

Reward-based crowdfunding, as it currently exists, can be viewed as another form of advance selling, except that an entrepreneur can sell to customers only after running a successful crowdfunding campaign. A vast body of literature has been published on quality signaling in advance selling, characterizing the potential drivers for different quality signaling mechanisms. For example, pricing has been identified as an important quality-signaling tool. In the presence of informed customers, when higher quality is associated with higher marginal costs, a high-quality firm can signal its type by setting a high price because informed customers make it costly for low-quality firms to mimic the high price (Bagwell and Riordan 1991). The literature on advance selling also predicts that when no informed customers are present, quality signaling through only the first-period price is not credible but needs capacity rationing (Yu et al. 2015) or price commitment (Chen and Jiang 2021). Given the nature of crowdfunding, it is innocuous to assume that potential backers are unaware of the true quality of the entrepreneur's product. Interestingly, even when well-established firms are behind crowdfunding campaigns, they try to hide their involvement (which can ensure the quality) with the project because it might discourage contributions to the project (Sayedi and Baghaie 2017). Under such asymmetric information circumstances, we want to investigate whether the quality signaling findings in advance selling settings still hold in a crowdfunding setting, recognizing similarities (price and selling in two periods) and differences (second-period selling occurs only if the first period's funding campaign is successful) between these settings.

Blaseg et al. (2020) have reported that among 34,745 crowdfunding campaigns in the field of technology and games, 90% of them only post funding prices, while the rest post retail prices along with their funding prices. For example, Table 1(a) shows a crowdfunding

Table 1: Crowdfunding Campaigns with and without Retail Price Commitment

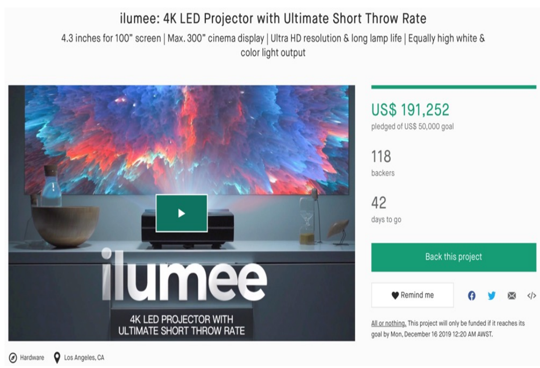
<table>
<tr><th></th><th>Reward-based Crowdfunding Campaign</th><th>Pricing Mechanism</th></tr>
<tr><td>(a) Without retail price commitment</td><td>
</td><td>Pledge $109 or more

Believer

Available colors 'Blue' 'Pink' or 'White'. We will contact after the campaign to pick the color you want.

INCLUDES:
• POMO WAFFLE Smartwatch
• 2× Waffle Band

ESTIMATED DELIVERY
Mar 2017
SHIPS TO
Anywhere in the world

Limited
123 backers</td></tr>
<tr><td>(b) With retail price commitment</td><td>
</td><td>Pledge $1,899 or more

ilumee projector Kickstarter Special

Enjoy your exclusive discount where you will get: ilumee 4K LED Projector * 1, Power Adapter * 1, Power Cable *1, Remote Control * 1
Will retail for $3,267 | 42% off retail

INCLUDES:
• ilumee 4K projector
• Power Adapter
• Power Cable
• Remote Control

ESTIMATED DELIVERY
May 2020
SHIPS TO
Anywhere in the world

1 backer</td></tr>
</table>

Source. https://www.kickstarter.com

campaign for a smartwatch, POMO Waffle, that only posts its funding price at $109, while Table 1(b) depicts a campaign that posts not only its funding price at $1899 but also the retail price of its product, ilumee, at $3267. Empirical studies have found that customers are not protected against entrepreneurs' price advertising claims (PACs) or retail prices in our second example. While we are agnostic on how the entrepreneur implements price commitment, researchers have called for regulatory intervention to monitor product prices in the regular selling period to protect the funding period customers (Blaseg et al. 2020). Moreover, given the continuous innovation in the crowdfunding industry, that price commitment would be introduced on crowdfunding platforms (Grell 2015) to protect campaign backers can be safely assumed. We investigate whether a high-quality entrepreneur can separate himself from a low-quality one by simply posting the funding price (one-price signaling) or whether he also needs to commit to the regular selling price (two-price signaling). If a separating equilibrium exists, is the driving force specific to the crowdfunding setting?

To answer these questions, we construct a two-period crowdfunding model in which the entrepreneur continues to sell to regular selling (second-period) customers only if the crowdfunding campaign is successful in the first period. Product quality is unknown to funding period customers, and entrepreneurs use different pricing mechanisms to signal their quality. In one-price signaling, the entrepreneur sets a funding price at the beginning of the first period (in two-price signaling, the entrepreneur posts his regular selling price). By observing the posted price (pair of prices), funding period customers update their beliefs about product quality and decide whether to contribute to the campaign. If the backers' contribution exceeds the campaign target level, the funding campaign succeeds, and the entrepreneur can collect funds to set up his business. At the beginning of the second period, the entrepreneur updates his belief on customer taste distribution and posts his regular selling price (if he has not yet committed to it). The second group of customers then arrives. They decide whether to buy based on the posted regular selling price and the revealed true product quality. We capture the difference between crowdfunding and advance selling by assuming that access to the regular selling period is contingent on the campaign's success in the funding period.

Our first finding shows that incorporating a regular selling period contingent on a successful crowdfunding campaign is crucial for quality signaling through the funding price. In such a setting, any distortion in the funding price not only affects the expected return in the funding period (direct effect) but also changes the expected return of the second period (indirect effect) through the changes in the probability of reaching the second period (i.e., the probability of a successful campaign). We show that a low-enough funding price could signal a high-quality level to funding period customers when the project's financing needs are not high. This is in contrast to the literature on advance selling, which predicts that just the first-period price is not a credible quality signaling tool (e.g., Chen and Jiang 2021, Yu et al. 2015). Specific to crowdfunding settings, the indirect effect of funding price lies at the core of this contrast. Given that the high-quality entrepreneur has a better prospect in the regular selling period than a low type (due to the revealed high quality), any changes in the funding price have different indirect effects on high- and mimicking low-quality entrepreneurs. In particular, we show that a downward distortion in the funding price has a larger positive indirect effect on the high-quality entrepreneur's profit (increases the probability of reaching the regular selling period and the expected profit associated with it) than a mimicking low-quality one. Thus, it reduces the signaling cost for high-quality entrepreneurs at low finding prices, allowing them to signal their quality through a sufficiently low funding price. The separating equilibrium arises as a unique Perfect Bayesian Equilibrium that survives the intuitive criterion.

Price commitment allows entrepreneurs to signal their quality for a wider range of financing needs compared to one-price signaling. Although contingent access to the second period is unnecessary for two-price signaling, the probabilistic nature of crowdfunding determines how high-quality entrepreneurs should manipulate their funding and regular selling prices. When the degree of information asymmetry (i.e., the gap in potential quality levels) is not large, the high-quality entrepreneur downward deviates the funding price from the optimal one in the full-information case, and upward distorts the regular selling price to signal his high quality. To explain this combination of price distortions for two-price signaling, note that commitment to a high regular selling price imposes a high opportunity cost of mimicking on a low-quality entrepreneur. A high-quality entrepreneur amplifies the expected opportunity cost of a mimicking low-quality entrepreneur by reducing his funding price, as a lower funding price increases the chance of reaching the regular selling period in our model. Such combined distortions reduce the high-quality entrepreneur's signaling costs in crowdfunding settings. As the degree of information asymmetry increases, a downward distortion in the funding price might be sufficient to signal a high-quality level.

The distinct feature of crowdfunding, i.e., the probabilistic nature of crowdfunding, plays different roles in one- and two-price signaling. It is the driving force for separating equilibrium in one-price signaling, as it introduces the indirect effect of funding price. This is not true for two-price signaling. Even when access to the regular selling period is certain (i.e., in the absence of the indirect effect), separating equilibrium still exists. Nevertheless, the probabilistic nature of crowdfunding dictates how the high-quality entrepreneur should distort both his funding and regular selling prices in two-price signaling. The extra available lever for quality signaling (i.e., the regular selling price) makes us expect the two-price mechanism to dominate the one-price signaling mechanism. Our numerical experiments shed light on when entrepreneurs should pursue price commitment amid its practical limitations and challenges. In particular, the entrepreneur benefits the most from price commitment when the degree of information asymmetry is large and the correlation between customers' valuations in the funding and regular selling periods is strong.

The rest of this paper is organized as follows. In Section 2, we review the relevant literature. In Section 3, we present the model and define the equilibrium concept. In Sections

4 and 5, we study one- and two-price signaling mechanisms, respectively. We compare the relative performance of these two signaling mechanisms in §6 and conclude in §7. All proofs are provided in Appendix A. We provide interested readers with discussions on the robustness of our findings and refinement of the pooling equilibrium in Online Supplement.

2. Literature Review

The success of online crowdfunding platforms has attracted the attention of numerous empirical researchers (Agrawal et al. 2015). Most of these studies examined potential factors contributing to the success of crowdfunding campaigns and issues that complicate crowdfunding campaign design (e.g., Blaseg et al. 2020, Mollick 2014, Zhang and Liu 2012, Freedman and Jin 2011). For a comprehensive overview of this literature, please refer to Belleflamme et al. (2015) and references therein.

In addition to empirical studies, a growing body of theoretical literature has been devoted to crowdfunding. Chang (2016) studies fixed and flexible crowdfunding campaigns. In the former, the contributed money would be refunded if the target investment level is not met, while in the latter, raised funds would be seized by the firm even if the campaign is a failure. They show that fixed campaigns generate more revenue, complementing borrowing because they help the firm learn its product market value. Du et al. (2019) study three stimulus policies: seeding, feature upgrade, and limited-time offer to improve the success probability of reward-based crowdfunding. Strausz (2017) argues that deferred payments and conditional pledges can eliminate the moral hazard problem associated with reward-based crowdfunding. Belavina et al. (2020) study fund misappropriation and performance opacity risks in reward-based crowdfunding and propose two mechanisms based on the deferred payment to mitigate such risks. Xu et al. (2019) develop a two-period model to study the effect of network externalities, social learning, and financial constraints between a reward-based crowdfunding entrepreneur and strategic customers. Finally, Kumar et al. (2020) show that crowdfunding can serve as a price-discrimination mechanism that forces funders to pay more. They show that when the cost of external financing decreases, creators might be encouraged to rely more on price discrimination and decrease their production. None of these studies examined quality issues that might arise in crowdfunding campaigns.

Empirical studies on crowdfunding have established that the underlying quality of a project has a direct effect on its crowdfunding campaign success (Mollick 2014). Hu et al. (2015) have conducted one of the pioneering theoretical studies on optimal product quality and pricing decisions in crowdfunding. They show that the fundraiser should offer different quality products if customers are sufficiently heterogeneous in their valuations. Sayedi and Baghaie (2017) study how entrepreneurs can signal their competency to customers. In particular, they show that customers benefit from not knowing the entrepreneur's competency level. Chakraborty and Swinney (2021)'s work is closer to our paper. They considered a model in which creators signal product quality via campaign design. Our study differs from theirs in several key ways: Most notably, Chakraborty and Swinney (2021) do not consider the regular selling period. In the absence of a regular selling period, they predict a unique pooling equilibrium for our model settings. Additionally, Chakraborty and Swinney (2021) assume a mix of informed and uninformed backers, which drives their insights. Given that we assume all funding period customers are uninformed about the quality level of the entrepreneur, the driving force for the separating equilibrium in our model is quite different from Chakraborty and Swinney (2021).

Most literature on crowdfunding overlooks the regular selling period for a detailed analysis of the funding period (e.g., Du et al. 2019). A growing body of literature has emphasized the importance of considering the regular selling period in crowdfunding campaign design (e.g., Xu et al. 2019, Sayedi and Baghaie 2017, Belavina et al. 2020), but this literature mostly overlooks the probabilistic nature of the funding period. To the best of our knowledge, the only exception is Chemla and Tinn (2020), who study learning in reward-based crowdfunding. Using a two-period model, they demonstrate how learning from the crowdfunding period creates a real option and helps the firm reduce moral hazard. In contrast to most existing literature, we model the probabilistic nature of crowdfunding campaigns in a two-period setting that incorporates funding and regular selling periods. This gives rise to several findings in stark contrast to the existing literature, and highlights the importance of incorporating these features (i.e., the probabilistic nature of the funding period and potential new sales after a successful campaign) into crowdfunding models.

Several different quality signaling mechanisms have been proposed in the literature, such as advertisement (Kihlstrom and Riordan 1984, Paul Milgrom 1986), scarcity (Stock and Balachander 2005), capacity rationing (Yu et al. 2015) and warranties (Lutz 1989), etc. Among these methods, quality signaling through pricing is closest to this study, which has received considerable attention in the literature (e.g., Rao and Monroe 1989, Bagwell and Riordan 1991, Moorthy and Srinivasan 1995). Bagwell and Riordan (1991) study quality signaling in a market where part of the customers are informed of the product quality while the rest are not. They show that high prices can signal high-quality levels when high-quality products are associated with higher production costs. As the ratio of informed customers increases over time, they show that high and declining prices signal high quality. In the absence of cost differences and in the presence of uninformed customers, Yu et al. (2015) and Chen and Jiang (2021) show that, in advance selling, quality signaling through the first-period price is not credible. Yu et al. (2015) introduce capacity rationing, and Chen and Jiang (2021) apply price commitment to signal quality. In this paper, we study one- and two-price quality signaling to uninformed customers in crowdfunding settings.

3. The Model

We study a risk-neutral entrepreneur (he) who launches a reward-based crowdfunding campaign to fund his project by pre-selling his product. The campaign is successful if the total funds raised in the campaign exceed a pre-announced threshold. If the set threshold is not met, the campaign fails, and all project backers get their money back. After a successful campaign, the entrepreneur must deliver the promised product to prepaid customers in the crowdfunding period (later referred to as the funding period). He may continue to sell in a regular selling period to a new set of customers whose taste of the product might be correlated with customers' taste in the funding period.

When the entrepreneur introduces the product on a crowdfunding platform, he knows the true quality of the product, while customers only receive product information through the online platform (e.g., ads, descriptions, and demos). Therefore, we assume that customers are uncertain about the product quality. Similar to most of the existing literature on asymmetric quality information (e.g., Moorthy and Srinivasan 1995, Lai et al. 2012), we assume that product quality can be either low (q_L) or high (q_H, $q_H > q_L$), which is private information to the entrepreneur at the beginning of the funding period, and potential backers (funding period customers) only hold a belief that the product is of high quality with probability a ($0 \leq a \leq 1$). High-quality entrepreneurs need to signal their quality type to customers and differentiate themselves from low-quality ones. We also assume that the entrepreneur's marginal production cost is the same for both types of product quality, and is normalized to zero. This assumption is common in the literature (e.g, Stock and Balachander 2005, Chen and Jiang 2021, Jiang and Tian 2018, Chakraborty and Swinney 2021): Srinivasan et al. (1997) show that, from a customer's perspective, higher design quality does not necessarily entail higher production costs. In addition, by normalizing the marginal production cost of both types to zero, we abstract away the role of cost differences in facilitating quality signaling (Bagwell and Riordan 1991, Chakraborty and Swinney 2021). In the rest of this section, we first describe the decisions of customers and the entrepreneur in each period, and then define the sequence of the signaling game.

3.1. Crowdfunding Period

At the beginning of the funding period, the entrepreneur introduces his product through demos and ads on a platform and posts his funding price along with a financing target level, $T > 0$. Customers check the project on the platform and decide whether to back it. If they choose to back, they can receive the promised product after a successful campaign, and their utility is $U_c = \theta_c q_j - p_1$, where θ_c denotes the customers' taste (valuation) in the funding period, p_1 is the funding price, and q_j is the perceived product quality. We assume that the funding period customers are homogeneous and share the same taste for the product θ_c, which is unknown to the entrepreneur. For an entrepreneur introducing an innovative product into the market, predicting how the product would be perceived by customers in the funding period and later in the retail market is challenging. For example, a singer working on his debut album cannot be sure of the audience's reaction to his music. Therefore, we assume that the taste parameter is uniformly distributed between 0 and 1, i.e., $\theta_c \sim U[0,1]$.

This model mainly focuses on products at a later stage of research and design (R&D), and hence, uncertainty on the features and cost of the project, such as video games and smartphone apps, is less. These products fit well with our following assumption on the financing target level: We follow Zhang et al. (2017) and Du et al. (2019) and assume that the funding target level T is exogenously given because it is the cash needed to set up the business. We also refer to T as the fixed cost required to move from the design and prototyping phases to full-scale production (Chakraborty and Swinney 2021).

The campaign will succeed if the funding period customers back the project and the raised funds exceed the campaign's financing target level T, i.e., $\theta_c q_j - p_1 \geq 0$, and $N_1 p_1 \geq T$, where N_1 is the market size in the funding period. The entrepreneur then receives the fund from the platform to set up his business and deliver the product to backers at the end of the funding period.

3.2. Regular Selling Period

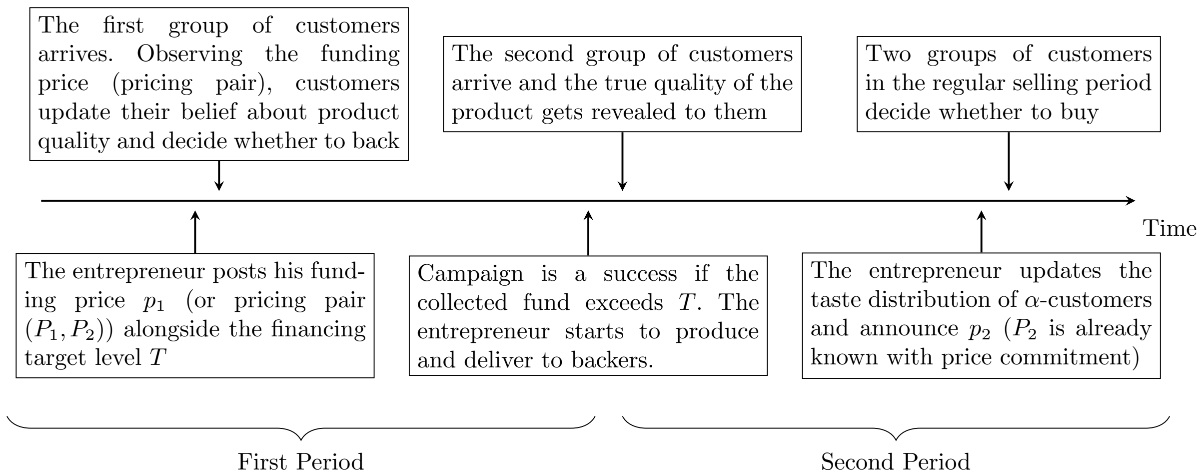
A successful entrepreneur, after delivering to his backers, can continue to produce and sell his product in a regular selling period (with market size N_2). Given that the final product is ready in the regular selling period, the true product quality q_i, $i \in \{H, L\}$, is revealed to the customers. The utility of purchasing the product for customers in the regular selling period is given by $U_r = \theta_r q_i - p_2$, where p_2 is the regular selling price, and θ_r is the customers' taste, as we elaborate next.

An entrepreneur can use his crowdfunding campaign design as a marketing research tool to uncover the potential market size or taste of customers in the regular selling market (Chemla and Tinn 2020, Sayedi and Baghaie 2017). To model such a connection between the funding and regular selling periods and the learning effect of the crowdfunding campaign, we assume that the valuations of customers in these two periods are correlated. In particular, we assume customers are heterogeneous in the second period. $100\alpha\%$ $(0 < \alpha < 1)$ of the regular selling period customers share the same taste as the funding period customers, i.e., their taste $\theta_{r\alpha}$ is the same as θ_c, while the product taste for the rest of the regular selling period customers θ_{rc}, is independent of θ_c. Without loss of generality, we also assume $\theta_{rc} \sim U[0,1]$. We refer to the former as α-customers, and the latter as common regular selling period customers. Consider a group of enthusiastic gamers interested in a particular type of game. Once a potentially attractive gaming project is launched on a crowdfunding platform, only some of these enthusiast gamers are likely to get informed about the project. After a successful campaign, when the game is introduced in the regular selling market, more gamers become aware of the game, as people discuss it on different game forums such as Steam Discussions or GameFAQs. We assume that these enthusiastic gamers share the same taste for the game, independent of when they find out about it because they are fans of this type of game. α-customers in the model represent the enthusiast gamers in the regular selling market that find out about the game on different social media platforms. Clearly, as α increases from zero to one, the correlation between customers' tastes in the funding and regular selling periods increases from zero to one. After a successful campaign, the distribution of α-customers' taste is updated to $\tilde{\theta}_{r\alpha} \sim U[\frac{p_1}{q_j}, 1]$.

3.3. The Game

We investigate whether an entrepreneur with a high-quality product can credibly separate himself from a low-quality type through pricing. We study two signaling mechanisms: one-price signaling, where the entrepreneur signals his quality through the funding price, and two-price signaling, where the entrepreneur also commits to the regular selling price at the beginning of the funding period.

Figure 1: Sequence of Events



In the first (second) scenario, the entrepreneur posts his price p_1 (pair of prices (P_1,P_2)[3]) and his target financing level, T. Then potential backers who are not aware of the true product quality arrive. Upon observing the entrepreneur's price (pair of prices), potential backers update their beliefs about the product quality. Let $a'(p_1)$ $(a'(P_1, P_2))$ denote customers' updated belief as a function of the price(s) offered by the entrepreneur at the beginning of the funding period. Based on their updated beliefs, customers decide whether to back the project by pre-purchasing the promised product. If backers contribute enough to the campaign, the entrepreneur collects the fund, starts to produce, and delivers the products to the pre-buyers at the end of the funding period. At the beginning of the regular selling period, the second group of customers arrives. Considering that the product is now available on the market, its true quality is revealed to them. The entrepreneur updates his belief over customers' taste (for α-customers) and posts the regular selling price (the regular selling price has been already committed under a two-price signaling mechanism). Based on their taste and the entrepreneur's posted price, both groups of customers in the regular selling period decide whether to buy. The sequence of events is depicted in Figure 1.

To tease out the effect of different market parameters (e.g., the gap in potential quality levels, the financing target levels, and the correlation between customers' tastes in the two periods) on equilibrium characterization and disentangle it from the effect of market size, we normalize the funding and regular selling market sizes to one, i.e., $N_1 = N_2 = 1$. The entrepreneur's objective is to maximize the total expected profit from the funding and

[3] We use capital letters for the two-price mechanism's notation.

regular selling periods. We set the discount rate in the second period to one and normalize the salvage value of unsold units to zero.

We use the Perfect Bayesian Equilibrium (PBE) to analyze two potential equilibrium outcomes: separating and pooling equilibrium. In a separating equilibrium, potential backers can perfectly separate the high-quality product from the low-quality one based on different funding prices (pair of prices), i.e., $a'(\cdot) = 0$ or 1. In a pooling equilibrium, both types of entrepreneurs set the same price (pair of prices), so backers cannot separate them, i.e., $a'(\cdot) = a$. We also assume that if a price (pair of prices) is off the equilibrium path, backers would believe the product quality is low, i.e., $a' = 0$. To limit the number of equilibria, we apply *intuitive criterion* introduced by Cho and Kreps (1987) to refine the set of equilibria.

4. Signaling through the Funding Price

This section analyzes the entrepreneur's signaling game through just the funding price. We first characterize the optimal regular selling price set by the entrepreneur after a successful crowdfunding campaign in §4.1. Then, we derive the optimal funding price for the entrepreneur in §4.2. The equilibrium funding price under asymmetric information is characterized in §4.3. Table 3 at the beginning of the Appendix summarizes all the notations used in this paper.

We first formulate the belief that the funding period customers hold to infer the product quality because it is private information to the entrepreneur. We focus on pure-strategy separating equilibrium ($a'(p_1) = 0$ or 1) in the following analysis, and the belief structure of the funding period customers is as follows:

$$q_j(p_1) = \begin{cases} q_H & \text{if } p_1 \in \mathbb{Q}, \\ q_L & \text{otherwise,} \end{cases} \tag{1}$$

where $\mathbb{Q}$ is a subset of $\mathbb{R}^+$. This belief structure indicates that if the observed funding price $p_1 \in \mathbb{Q}$, then the funding period customers believe the quality of the product is high; otherwise, the funding period customers believe that the quality is low. In the next subsection, we study the optimal price in the regular selling period. While the true product quality q_i is revealed to customers at the beginning of the regular selling period, the optimal price in the regular selling period can be a function of customers' prior belief on quality, q_j. This is because the entrepreneur updates his belief on α-customers' taste distribution in the regular selling period based on the campaign success in the funding period.

4.1. Regular Selling Period Price

After a successful campaign, the entrepreneur updates the taste distribution of α-customers in the regular selling period to $\tilde{\theta}_{r\alpha} \sim U[\frac{p_1}{q_j}, 1]$ because their taste is the same as customers' taste in the funding period, θ_c. Therefore, the expected profit of the entrepreneur in the regular selling period, after a successful campaign and revelation of the true quality q_i is

$$\pi_2^{ij}(p_2|T \leq p_1 \leq q_j) = \begin{cases} \alpha p_2 + (1-\alpha)(1-\frac{p_2}{q_i})p_2 & 0 < p_2 < \frac{p_1 q_i}{q_j}, \\ \frac{\alpha}{1-p_1/q_j}(1-\frac{p_2}{q_i})p_2 + (1-\alpha)(1-\frac{p_2}{q_i})p_2 & \frac{p_1 q_i}{q_j} \leq p_2 \leq q_i. \end{cases} \tag{2}$$

If the entrepreneur sets a low regular selling price (i.e., $0 < p_2 < \frac{p_1 q_i}{q_j}$), the utility of α-customers, given by $\tilde{\theta}_{r\alpha} q_i - p_2$ is always positive, so α-customers would purchase for sure. If the entrepreneur sets a large regular selling price (i.e., $\frac{p_1 q_i}{q_j} \leq p_2 \leq q_i$), the purchase probability of α-customers would be $\frac{1}{1-p_1/q_j}(1-\frac{p_2}{q_i})$, and the entrepreneur could take advantage of the updated distribution of $\tilde{\theta}_{r\alpha}$ to set his regular selling price. For the common regular selling period customers, their taste distribution remains the same, $\theta_{rc} \sim U[0,1]$ as the crowdfunding success does not reveal any information on their taste parameter. The purchase probability for these customers is $(1-\frac{p_2}{q_i})$ and the entrepreneur's expected payoff from these customers is given by $(1-\alpha)(1-\frac{p_2}{q_i})p_2$ for $p_2 \in [0, q_i]$.

The following lemma characterizes the optimal price and the expected profit of the entrepreneur in the regular selling period as a function of the campaign success target T.

LEMMA 1. *i) When the campaign success target is low, i.e., $T < \frac{q_j}{2}$, the optimal regular selling price p_2^{ij*} and the corresponding expected profit of the entrepreneur π_2^{ij*}, given the funding price $p_1 \geq T$, are given by*[4]

$$\left(p_2^{ij*}, \pi_2^{ij*}\right) = \begin{cases} \left(\frac{q_i}{2}, (\frac{\alpha}{1-p_1/q_j} + (1-\alpha))\frac{q_i}{4}\right) & T \leq p_1 < \frac{q_j}{2}, \\ \left(\frac{p_1 q_i}{q_j}, \frac{\alpha p_1 q_i}{q_j} + (1-\alpha)(1-\frac{p_1}{q_j})\frac{p_1 q_i}{q_j}\right) & \frac{q_j}{2} \leq p_1 < \frac{q_j}{2(1-\alpha)} \wedge q_j, \\ \left(\frac{q_i}{2(1-\alpha)}, \frac{\alpha q_i}{2(1-\alpha)} + (1-\frac{1}{2(1-\alpha)})\frac{q_i}{2}\right) & \frac{q_j}{2(1-\alpha)} \wedge q_j \leq p_1 \leq q_j. \end{cases} \tag{3}$$

ii) When the campaign success target is relatively high, i.e., $\frac{q_j}{2} \leq T < \frac{q_j}{2(1-\alpha)} \wedge q_j$, $\left(p_2^{ij*}, \pi_2^{ij*}\right)$ is the same as (3) with the first case excluded and the condition on the second case changed to $T \leq p_1 < \frac{q_j}{2(1-\alpha)} \wedge q_j$.

iii) When the campaign success target is high, i.e., $\frac{q_j}{2(1-\alpha)} \wedge q_j \leq T \leq q_j$, $\left(p_2^{ij*}, \pi_2^{ij*}\right)$ is the same as (3) with the first two cases excluded and the condition on the third case changed to $T \leq p_1 \leq q_j$.

[4] We use the following notation, $x \vee y = \max(x, y)$, $x \wedge y = \min(x, y)$, to simplify our exposition.

As discussed in §3.1, $p_1 \geq T$ is necessary for the campaign success as we have normalized the funding period market size to one. Lemma 1 indicates that large financing needs just narrow down the range of p_1 (and thus the range of the threshold on the probabilistic sale to α-customers, $\frac{p_1 q_i}{q_j}$), rather than the functional forms of p_2^{ij*} and π_2^{ij*} in each case. Case i) of Lemma 1 provides the full picture of the trade-offs the entrepreneur faces when he sets the regular selling price. When p_1 is not large, the maximum p_2 that guarantees selling to α-customers is relatively small. The entrepreneur updates his belief on these customers' valuation, $\tilde{\theta}_{r\alpha}$, and solves the second case of (2) to find the optimal price in the regular selling period. For large values of the funding price, the maximum p_2 that guarantees a sale to α-customers is also large. The entrepreneur sets a lower regular selling price that not only guarantees selling to α-customers but also attracts common customers because their taste is independent of the α-customers' valuation. The optimal regular selling price is the one that maximizes the first case of (2), i.e., $p_2 = \frac{q_j}{2(1-\alpha)}$. This case only happens when the percentage of common customers in the regular selling period is larger than the α-customers, i.e., $\alpha < \frac{1}{2}$. For moderate values of p_1 (i.e., when $\frac{q_j}{2} \leq p_1 < \frac{q_j}{2(1-\alpha)} \wedge q_j$), the entrepreneur adopts $p_2 = \frac{p_1 q_i}{q_j}$ to guarantee selling to α-customers, knowing that this price is relatively attractive for the common regular selling period customers (notably, $\frac{p_1 q_i}{q_j} \leq \frac{q_j}{2(1-\alpha)}$).

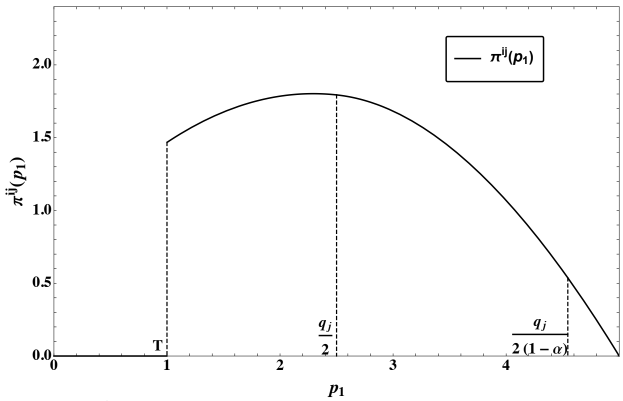
4.2. Crowdfunding Price

Moving backward, we study the entrepreneur's pricing strategy in the funding period when customers believe the project quality is q_j, $j \in \{H, L\}$. Anticipating his expected profit in the regular selling period, as characterized in Lemma 1, the entrepreneur, with true quality q_i when he is believed to be of type q_j, maximizes the following objective function at the beginning of the funding period, when $T < \frac{q_j}{2}$,

$$\max_{p_1 \geq T} \ \pi^{ij}(p_1) = Pr(\theta_c q_j - p_1 \geq 0)(p_1 + \pi_2^{ij*})$$
$$= \begin{cases} (1 - \frac{p_1}{q_j})(p_1 + (\frac{\alpha}{1-p_1/q_j} + (1-\alpha))\frac{q_i}{4}) & T \leq p_1 < \frac{q_j}{2}, \\ (1 - \frac{p_1}{q_j})(p_1 + \frac{\alpha p_1 q_i}{q_j} + (1-\alpha)(1 - \frac{p_1}{q_j})\frac{p_1 q_i}{q_j}) & \frac{q_j}{2} \leq p_1 < \frac{q_j}{2(1-\alpha)} \wedge q_j, \\ (1 - \frac{p_1}{q_j})(p_1 + \frac{\alpha q_i}{2(1-\alpha)} + (1 - \frac{1}{2(1-\alpha)})\frac{q_i}{2}) & \frac{q_j}{2(1-\alpha)} \wedge q_j \leq p_1 \leq q_j. \end{cases} \tag{4}$$

Similarly, when $\frac{q_j}{2} \leq T < \frac{q_j}{2(1-\alpha)} \wedge q_j$ (respectively, when $\frac{q_j}{2(1-\alpha)} \wedge q_j \leq T \leq q_j$), the expected profit function of the entrepreneur $\pi^{ij}(p_1)$ excludes the first case (and the second cases) of the piece-wise function in (4), and conditions on the funding price change as in cases (ii) and (iii) of Lemma 1. Figure 2 demonstrates the profit curve of $\pi^{ij}(p_1)$ when $T < \frac{q_j}{2}$, which

Figure 2: Illustration of the entrepreneur's expected profit $\pi^{ij}(p_1)$ when $T < \frac{q_j}{2}$



Notes. The parameters are $q_i = 3$, $q_j = 5$, $\alpha = 0.45$, $T = 1$.

includes all the three cases. When $T < \frac{q_j}{2}$, $\pi^{ij}(p_1)$ is concave in p_1 over $T \le p_1 < \frac{q_j}{2}$, and decreases in p_1 over $\frac{q_j}{2} \le p_1 < \frac{q_j}{2(1-\alpha)} \wedge q_j$ and $\frac{q_j}{2(1-\alpha)} \wedge q_j \le p_1 \le q_j$. Larger financing target just shrinks the range of p_1 but not the functional forms.

The funding price has three effects on the entrepreneur's expected profit. First, it determines the entrepreneur's expected payoff in the funding period. Second, the funding price affects the entrepreneur's pricing strategy in the regular selling period and thus the expected payoff in the second period, as demonstrated in Lemma 1. Third, it affects the probability of the crowdfunding campaign's success, i.e., $Pr(\theta_c q_j - p_1 \ge 0)$, and lower funding prices induce higher campaign success probabilities. As we will demonstrate in the next subsection, higher campaign success probabilities due to lower funding prices are crucial to separate the high-quality entrepreneurs from the low-quality ones in the one-price signaling mechanism. Before carrying out the equilibrium analysis, we first characterize the optimal funding and regular selling period prices for the entrepreneur with true quality q_i when he is believed to be of quality q_j in the following lemma.

LEMMA 2. *$\pi^{ij}(p_1)$ is uni-modal in the funding price $p_1 \in [T, q_j]$, and is maximized at $p_1^{ij*} = \max\{\frac{4q_j-(1-\alpha)q_i}{8}, T\}$. The corresponding optimal regular selling price is given by*

$$p_2^{ij*} = \begin{cases} \frac{q_i}{2} & 0 < T \le \frac{q_j}{2}, \\ \frac{Tq_i}{q_j} & \frac{q_j}{2} < T < \frac{q_j}{2(1-\alpha)} \wedge q_j, \\ \frac{q_i}{2(1-\alpha)} & \frac{q_j}{2(1-\alpha)} \wedge q_j \le T \le q_j. \end{cases}$$

According to Lemma 2, it is straightforward to characterize the entrepreneur's pricing strategy in the funding and the regular selling periods under full information by setting $j = i = \{H, L\}$. For instance, the optimal funding price for an entrepreneur of type i is $p_{1f}^{i*} = \max\{\frac{(3+\alpha)}{8}q_i, T\}$, where the subscript f stands for the full-information case. An interesting observation about the optimal funding price under the full-information case is that as the correlation between customers' tastes in the funding and regular selling periods increases (i.e., as α increases), the entrepreneur increases his optimal funding price. When customers' tastes in the two periods are independent, the entrepreneur sets a lower funding price as the success in the first period does not reveal any information on the second period's potential payoff. Regardless of the customers' taste in the funding period, reaching the second period is enticing. In the presence of a positive correlation, a successful campaign is more desirable when it also reveals a high potential valuation for α-customers in the regular selling period. Similarly, a failure might be favorable for the entrepreneur if it implies a low valuation for α-customers in the second period. By increasing his funding price, the entrepreneur can benefit from the correlation between customers' tastes in the two periods. However, under asymmetric information, the high-quality entrepreneur cannot set the equilibrium funding price as the one characterized in the full-information case, i.e., p_{1f}^{H*}, because mimicking the high-quality entrepreneur is profitable for the low-quality one, and funding period customers cannot separate. Therefore, the high-quality entrepreneur needs to deviate from p_{1f}^{H*} in a separating equilibrium, which we study in the following subsection.

4.3. Equilibrium Characterization and Implications

In a separating equilibrium, the quality of the entrepreneur will be revealed to funding period customers because low- and high-quality entrepreneurs set different funding prices. It is straightforward to show that in a separating equilibrium, the funding price set by a low-quality entrepreneur is always the same as the one in the full-information case, i.e., $p_{1se}^{L} = p_{1f}^{L*}$ (the subscript se stands for separating equilibrium), as the above strategy yields the highest payoff for the low-quality entrepreneur (Lutz 1989, Yu et al. 2015). For the high-quality entrepreneur, the problem he needs to solve is as follows:

$$\max_{p_1 \geq T,\ p_1 \neq p_{1se}^{L}} \ \pi^{H}(p_1)$$

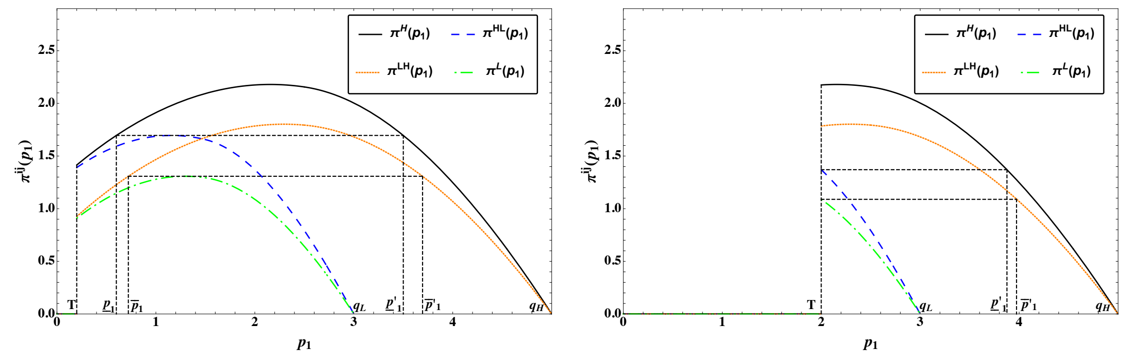
$$s.t.\ \pi^{LH}(p_1) \leq \pi^{L*}, \tag{5}$$

$$\pi^{H}(p_1) \geq \pi^{HL*}, \tag{6}$$

where $\pi^{ij}(p_1)$, $i,j=\{H,L\}$, is given in (4)[5], $\pi^{L*}=\pi^{L}(p_{1f}^{L*})$ and $\pi^{HL*}=\pi^{HL}(p_1^{HL*})$. The constraint in (5) is the necessary condition that guarantees a low-quality entrepreneur has no incentive to mimic the high-quality type's funding price to be perceived as a high-quality one. The constraint in (6) is the sufficient condition that makes sure that deviation

[5] To simplify the notation, we reduce the superscript ij to i for $\pi^{ij}(\cdot)$ and p^{ij} when $i=j$. Similar convention is used later for $\Pi^{ij}(\cdot)$, $V^{ij}(\cdot)$, $W^{ij}(\cdot)$ and P^{ij}.

Figure 3: Profit functions for the entrepreneur with no price commitment (color online)



(a) $T \leq \overline{p}_1$ (b) $T > \overline{p}_1$

Notes. The separating equilibrium $p_{1se}^{H} = \overline{p}_1$ where $q_L = 3$, $q_H = 5$, $\alpha = 0.45$, $T = 0.2$ for (a) and no separating equilibrium when $q_L = 3$, $q_H = 5$, $\alpha = 0.45$, $T = 2$ for (b).

from the equilibrium funding price is not profitable for the high-quality entrepreneur. If a funding price for the high-quality entrepreneur satisfies the *necessary and sufficient conditions* (N&S conditions, hereafter), the belief set $\mathbb{Q}$ in (1) is not empty and a separating equilibrium exists. Under this belief structure, the entrepreneur's funding period pricing strategy with either quality type is consistent with the funding period customers' belief. The following lemma demonstrates the existence of p_1 that satisfies the N&S conditions, helping us characterize the separating equilibrium.

LEMMA 3. *A unique $\underline{p}_1$ exists such that for $T \leq \underline{p}_1$:*

i) There are unique $\overline{p}_1$ and $\overline{p}'_1$ that satisfy $\pi^{L*} = \pi^{LH}(\overline{p}_1) = \pi^{LH}(\overline{p}'_1)$ with $\overline{p}_1 < p_1^{L*} < \overline{p}'_1$.

ii) There exists a unique $\underline{p}'_1$ that satisfies $\pi^{HL*} = \pi^{H}(\underline{p}_1) = \pi^{H}(\underline{p}'_1)$ with $\underline{p}_1 < p_1^{HL*} < \underline{p}'_1$.

iii) Moreover, $\overline{p}_1 > \underline{p}_1$ and $\overline{p}'_1 > \underline{p}'_1$.

Part (i) of Lemma 3 indicates that if the high-quality entrepreneur sets an equilibrium price $p_1 < \overline{p}_1$ or $p_1 > \overline{p}'_1$, the low-quality entrepreneur has no incentive to mimic p_1 because he earns more by revealing his low quality to customers as $\pi^{LH}(p_1) < \pi^{L*}$. Similarly, part (ii) demonstrates that in a separating equilibrium, the high-quality entrepreneur must set a funding price that satisfies $\underline{p}_1 \leq p_1 \leq \underline{p}'_1$. If in a separating equilibrium $p_1 < \underline{p}_1$ or $p_1 > \underline{p}'_1$, the high-quality entrepreneur has the incentive to deviate from p_1 to be perceived as a low-quality entrepreneur, as $\pi^{H}(p_1) < \pi^{HL*}$ over these ranges.

Part (iii) of Lemma 2 has important implications for the separating equilibrium characterization. Given that $\overline{p}_1 > \underline{p}_1$, a feasible range for the funding price p_1 exists, i.e., $[\underline{p}_1, \overline{p}_1]$ that satisfies the N&S conditions for the high-quality entrepreneur. If a high-quality entrepreneur charges a price in this range, the low-quality entrepreneur does not have any incentive to mimic it. Similarly, the high-type entrepreneur cannot increase his profit by charging a price out of this range because deviation results in customers believing that the entrepreneur is of low quality. This observation has been depicted in Figure 3(a). Similarly, we can check the range $[\underline{p}_1', \overline{p}_1']$ does not satisfies the N&S condition. Therefore, $p_1 \in [\underline{p}_1, \overline{p}_1]$ is the only feasible (non-empty) range for the high-quality entrepreneur that satisfies the N&S conditions. Lemma 3 also demonstrates how the required financing level affects the feasible range for the high-quality entrepreneur's funding price in the separating equilibrium. Since the funding price is bounded from the bottom by T, the feasible range for the high-quality entrepreneur would be empty if $T > \overline{p}_1$, which is depicted in Figure 3(b).

The finding that $\overline{p}_1 > \underline{p}_1$ guarantees the existence of a market belief under which the entrepreneur's strategy is consistent with the market belief, thus resulting in a separating equilibrium. Multiple equilibria (including pooling equilibria) exist in our settings, and the following proposition characterizes the unique separating equilibrium that survives the intuitive criterion (Cho and Kreps 1987). The intuitive criterion tests the stability of an equilibrium in a signaling game. Specifically, this criterion checks whether an alternative pricing level exists that the high (low)-quality entrepreneur will strictly prefer (not prefer) to the equilibrium funding price, assuming the deviation to the alternative funding price makes customers believe that he is of high quality. The insights from such an instable equilibrium may lose generality (Lai et al. 2012).

Proposition 1. *When $T \leq \overline{p}_1$, just a unique separating equilibrium survives the intuitive criterion refinement in which the funding prices are given by $p_{1se}^H = \overline{p}_1 = \frac{4q_H - (1-\alpha)q_L - \sqrt{(q_H - q_L)(16q_H - (1-\alpha)^2 q_L)}}{8}$ and $p_{1se}^L = \frac{3+\alpha}{8} q_L$ for the high- and low-quality entrepreneurs, respectively. Otherwise, only a pooling equilibrium exists.*

Proposition 1 implies that a separating equilibrium arises as the unique credible PBE whenever the financing requirement of the project is not high (i.e., $T \leq \overline{p}_1$). The high-quality entrepreneur can separate himself from a low-quality one through a low-enough funding price (part (i) of Lemma 3 indicates that $p_{1se}^H < p_{1se}^L$, i.e., in the separating equilibrium, the funding price set by the high-quality entrepreneur is lower than the price set by the low-quality one). As we discuss next, quality signaling through a low funding price is specific to the crowdfunding settings. The finding also has important implications in practice. A high-quality entrepreneur should avoid posting high funding prices because low-quality entrepreneurs have the incentive to mimic high funding prices, preventing credible signaling to the funding period customers.

We study two reference models to shed light on potential driving forces of the separating equilibrium in our crowdfunding settings. First, we investigate a one-period crowdfunding model similar to Chakraborty and Swinney (2021), in which no regular selling period occurs after a funding campaign. For an exogenous financing target level, Chakraborty and Swinney (2021) show that just a pooling equilibrium would exist if all the funding period customers are uninformed about the true quality of the project. Our first reference model confirms their finding by showing that in the absence of a regular selling period, the pooling equilibrium survives the intuitive criterion (Online Supplement C.1), and arises as the unique PBE that survives the lexicographically maximum sequential equilibrium (LMSE) refinement, introduced by Mailath et al. (1993).

In the second reference model, we incorporate the regular selling period. Unlike our crowdfunding model, the entrepreneur can sell in the regular selling period independent of the campaign's success in the funding period. This setting is similar to quality signaling in advance selling without price commitment so that the entrepreneur can still update his belief on α-customers' taste distribution, even after a failed funding campaign. Like the first reference model, the second reference model confirms that the pooling equilibrium survives the intuitive criterion refinement and arises as the unique equilibrium that survives the LMSE refinement (Online Supplement C.2). The result in the second reference model is consistent with the literature on quality signaling in advance selling that just the first-period price is not a credible quality signaling tool (Yu et al. 2015). As Chen and Jiang (2021) show, if just the first-period price is used for quality signaling, only a pooling equilibrium survives the LMSE refinement.

Comparing these reference models with our crowdfunding model, we can identify two distinct features of the crowdfunding model that pave the path for quality signaling: incorporating the regular selling period (the first reference model) and the probabilistic nature of the funding period (the second reference model). By incorporating a regular selling period contingent on a successful funding campaign in the first period, any distortion in the funding price has two effects on the entrepreneur's expected profit. In addition to a direct effect on expected return in the first period (i.e., $p_1(1 - p_1/q_j)$), any change in the funding price has an indirect effect on expected return from the second period (i.e., $(1 - p_1/q_j)\pi_2^{ij*}$) because it changes the probability of reaching the second period through the campaign's success probability, $(1 - p_1/q_j)$. Any downward distortion of the funding price has the same direct effects on the high- and mimicking low-quality entrepreneurs' profits. However, such distortion has a more favorable positive indirect effect on the high-quality entrepreneur's profit. A lower funding price increases the chance of reaching the second period. The regular selling period entails a clear advantage for the high-quality entrepreneur that offers a high-quality product. That is, $(1-p_1/q_H)\pi_2^{H*}-(1-p_1/q_H)\pi_2^{LH*}$ decreases in the funding price. A larger positive indirect effect of reducing the funding price alleviates the high-quality entrepreneur's signaling cost at low funding prices, allowing him to separate himself from a mimicking low-type at a sufficiently low funding price.

This finding contradicts the existing literature that predicts a pooling equilibrium as the only credible PBE in advance selling settings (Yu et al. 2015, Chen and Jiang 2021). The distinct feature of the crowdfunding model that results in such a contrast is the contingency of the second period on the first period's success, which introduces the indirect effect of pricing in the funding period. Such an effect is absent in advance selling, where reaching the second period is certain. In the absence of the indirect effect of the first-period pricing, the literature has shown that the first-period price alone cannot serve as a credible quality signaling mechanism. For the high-quality entrepreneur, the alleviated cost of distortion towards lower funding prices (due to the indirect effect) also results in refinement of the pooling equilibrium (Online Supplement D.1). This allows the separating equilibrium to arise as the unique PBE that survives the intuitive criterion refinement.

The characterized equilibrium funding prices in Proposition 1 allow us to investigate how the correlation between customers' tastes in the funding and regular selling periods affects the equilibrium funding prices. It is straightforward to show that $\frac{dp_{1se}^H}{d\alpha}\geq 0$, i.e., the equilibrium funding price for the high-quality entrepreneur increases with the correlation between customers' tastes in the two periods. This is in line with our previous finding under full information. The major driver for such an observation is that a stronger correlation in customers' tastes increases the equilibrium funding price of the low-quality entrepreneur, reducing the downward pressure on the equilibrium funding price of the high-quality one. Next, we can also show that the distortion in funding price from the full-information funding price also increases in α, i.e., $\frac{d(p_{1f}^{H*}-p_{1se}^H)}{d\alpha}\geq 0$. Although both of these funding prices (i.e., p_{1f}^{H*} and p_{1se}^H) increase in α, the price distortion for the high-quality entrepreneur is also increasing in α. A stronger correlation in customers' tastes increases the value of the regular selling periods for both types of entrepreneurs. Therefore, the high-quality entrepreneur needs to distort his funding price even more to prevent the low type's imitation.

As discussed, the high-quality entrepreneur might be able to signal his product quality in crowdfunding just through his funding price. However, our characterization of the separating equilibrium reveals two shortcomings of the one-price signaling mechanism: the campaign's target level needs not be large, and the signaling cost due to price distortion (i.e., $p_{1f}^{H*} - p_{1se}^{H}$) is high (note that $p_{1se}^{H} < p_{1se}^{L}$). Next, we investigate whether the commitment to the regular selling price is also a viable quality signaling mechanism. We also investigate whether signaling through price commitment can address the above two shortcomings of one-price signaling.

5. Signaling through Price Commitment

This section studies signaling through price commitment at the beginning of the funding period. First, we characterize the entrepreneur's problem under price commitment in §5.1. Then, we describe the feasible region for the high-quality entrepreneur's equilibrium pricing pair and the refined separating equilibrium in §5.2.

5.1. The Entrepreneur's Problem under Price Commitment

Similar to the previous signaling mechanism, we focus on pure-strategy separating equilibrium ($a'(P_1, P_2) = 0$ or 1) and formulate the belief structure of the funding period customers as

$$q_j(P_1, P_2) = \begin{cases} q_H & \text{if } (P_1, P_2) \in \mathbb{Q}', \\ q_L & \text{otherwise,} \end{cases} \tag{7}$$

where $\mathbb{Q}'$ is a subset of $\mathbb{R}^{2+}$. This belief structure indicates that if the observed pricing pair $(P_1, P_2) \in \mathbb{Q}'$, the funding period customers would believe that the product quality is high. Otherwise, they believe the product is of low quality. The entrepreneur forgoes his pricing flexibility in the second period by committing to the regular selling price at the beginning of the funding period. However, the entrepreneur knows that he would reach the regular selling period only when the funding campaign succeeds (i.e., $\theta_c q_j - P_1 \geq 0$), where q_j is the perceived quality as it is characterized in (7). Therefore, he can update his belief about the distribution of α-customers' taste to $\tilde{\theta}_{r\alpha} \sim U[\frac{P_1}{q_j}, 1]$ when he commits to P_2; otherwise, there would not be a regular selling period as the funding campaign fails.

Similar to one-price signaling, when the committed regular selling price is low enough (i.e., $0 < P_2 \leq \frac{P_1 q_i}{q_j}$), the α-customers purchase for sure after a successful campaign. To simplify the exposition of the entrepreneur's expected profit, we define the following functions:

$$V^{ij}(P_1, P_2) = (1 - \tfrac{P_1}{q_j}) \left(P_1 + \alpha P_2 + (1-\alpha)(1 - \tfrac{P_2}{q_i}) P_2 \right), i, j = \{H, L\},$$

where q_i is the true product quality and $V^{ij}(P_1, P_2)$ represents the entrepreneur's expected profit when α-customers purchase for sure. When the committed regular selling price is relatively high (i.e., $\frac{P_1 q_i}{q_j} < P_2 \le q_i$), α-customers purchase the product with the probability of $\frac{1-P_2/q_i}{1-P_1/q_j}$. Similarly, we define the following functions:

$$W^{ij}(P_1, P_2) = (1-\tfrac{P_1}{q_j})\left(P_1 + \tfrac{\alpha}{1-P_1/q_j}(1-\tfrac{P_2}{q_i})P_2 + (1-\alpha)(1-\tfrac{P_2}{q_i})P_2\right), i, j = \{H, L\},$$

to represent the entrepreneur's expected profit when P_2 is relatively high. In $V^{ij}(P_1, P_2)$ and $W^{ij}(P_1, P_2)$, $(1-\frac{P_1}{q_j})$ represents the campaign success probability, and $(1-\alpha)(1-\frac{P_2}{q_i})P_2$ denotes the expected profit from the common regular selling period customers. Combining these two cases, the expected profit of an entrepreneur with the true quality q_i and believed as q_j, when $i = j$, is given as

$$\Pi^i(P_1, P_2) = \begin{cases} V^i(P_1, P_2) & P_2 \vee T \le P_1 \le q_i, \\ W^i(P_1, P_2) & T \le P_1 < P_2 \vee T. \end{cases} \tag{8}$$

When $i \ne j$, profit functions are given by

$$\Pi^{HL}(P_1, P_2) = \begin{cases} V^{HL}(P_1, P_2) & T \le P_1, 0 < P_2 \le \frac{P_1 q_H}{q_L}, \\ W^{HL}(P_1, P_2) & T \le P_1, \frac{P_1 q_H}{q_L} < P_2 \le q_H, \end{cases} \tag{9}$$

$$\Pi^{LH}(P_1, P_2) = \begin{cases} V^{LH}(P_1, P_2) & \frac{q_H P_2}{q_L} \vee T \le P_1 < q_H, 0 < P_2 \le q_L, \\ W^{LH}(P_1, P_2) & T \le P_1 < \frac{q_H P_2}{q_L} \vee T, 0 < P_2 \le q_L, \\ (1-\frac{P_1}{q_H})P_1 & T \le P_1, q_L < P_2 \le q_H. \end{cases} \tag{10}$$

In the full-information case, the low-quality entrepreneur does not have any incentive to set $P_2 > q_L$, as q_L is the maximum regular selling price he can charge. Otherwise, no regular selling period customers would purchase. However, under asymmetric information, the low-quality entrepreneur might have the incentive to mimic the high-quality entrepreneur's regular selling price to set $q_L < P_2 \le q_H$, if it makes funding period customers believe that the product is of high quality. This occurs when the gain from being treated as a high-quality type in the funding period covers the loss of no sales in the regular selling period. In that case, $\Pi^{LH}(P_1, P_2) = (1-\frac{P_1}{q_H})P_1$, which is depicted as the third case in (10). Next, we characterize the optimal pricing decision of an entrepreneur of quality q_i who is believed to be of quality q_j in the following lemma.

Lemma 4. *Under price commitment, the optimal funding and regular selling prices for an entrepreneur with true quality q_i when he is believed to be of quality q_j, $i, j = \{H, L\}$, are given respectively by $P_1^{ij*} = \max\{\frac{4q_j - (1-\alpha)q_i}{8}, T\}$ and*

$$P_2^{ij*} = \begin{cases} \frac{q_i}{2}, & 0 < T \le \frac{q_j}{2}, \\ \frac{T q_i}{q_j}, & \frac{q_j}{2} < T < \frac{q_j}{2(1-\alpha)}, \\ \frac{q_i}{2(1-\alpha)}, & \frac{q_j}{2(1-\alpha)} \le T \le q_j. \end{cases} \tag{11}$$

A quick comparison between Lemmas 2 and 4 indicates that the optimal funding and regular selling prices are the same under both mechanisms with/without price commitment. The information revealed to the entrepreneur after a successful campaign in the one-price mechanism or by assuming a successful campaign in the two-price mechanism (i.e., $\tilde{\theta}_{r\alpha} \sim [\frac{p_1}{q_j}, 1]$ and $\tilde{\theta}_{r\alpha} \sim U[\frac{P_1}{q_j}, 1]$, respectively) is the same. Although the entrepreneur can take advantage of pricing flexibility in the first case, he can commit to the regular selling price by assuming that the campaign is successful. Therefore, unsurprisingly, the pricing strategy for the entrepreneur stays the same under both mechanisms. However, under asymmetric information, the equilibrium pricing strategy of the high-quality entrepreneur with price commitment is markedly different from the characterized equilibrium prices without price commitment in Proposition 1, as we demonstrate next.

5.2. Equilibrium Characterization under Price Commitment

Following the same argument as the one-price signaling case, in any separating equilibrium with price commitment, the pricing strategy of the low-quality entrepreneur is always the same as the optimal one in the full-information case, i.e., $(P_{1se}^L, P_{2se}^L) = (P_{1f}^{L*}, P_{2f}^{L*})$, as characterized in Lemma 4. The problem that the high-quality entrepreneur needs to solve is as follows:

$$\max_{(P_1,P_2)\neq(P_{1se}^L,P_{2se}^L), P_1\geq T} \Pi^H(P_1,P_2) \tag{12}$$

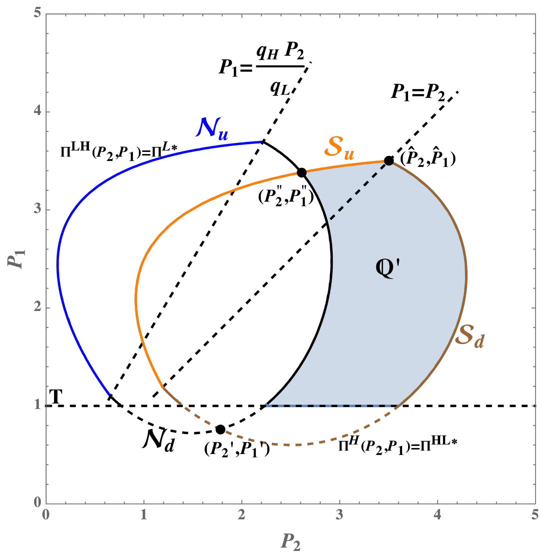
$$s.t.\ \Pi^{LH}(P_1,P_2) \leq \Pi^{L*}, \tag{13}$$

$$\Pi^H(P_1,P_2) \geq \Pi^{HL*}, \tag{14}$$

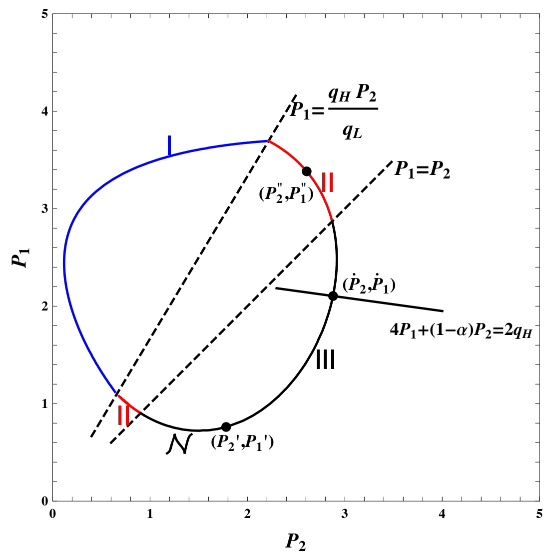
where $\Pi^{L*} = \Pi^L(P_{1f}^{L*}, P_{2f}^{L*})$ and $\Pi^{HL*} = \Pi^{HL}(P_1^{HL*}, P_2^{HL*})$. Similar to the one-price signaling case, a pricing pair (P_1, P_2) that satisfies constraints (13) and (14) lies in the feasible region for the high-quality entrepreneur in a separating equilibrium, which is also consistent with the belief structure defined in (7). Constraint (13) ensures the low-quality entrepreneur has no incentive to imitate the high-quality one's equilibrium pricing strategy, and constraint (14) indicates the high-quality entrepreneur has no incentive to deviate from the equilibrium pricing strategy. We first study whether a pricing pair (P_1, P_2) exists that satisfies constraints (13) and (14), by investigating the "single-crossing property" of the iso-profit curves (Athey 2001). Considering the piece-wise characteristic of the profit functions, we study the iso-profit curves under different conditions. We let $\mathcal{N}$ denote the iso-profit curve for the low-quality entrepreneur, and define $\mathcal{N}_u$ and $\mathcal{N}_d$ as

$$\mathcal{N}_u : \frac{q_H P_2}{q_L} < P_1 \leq q_H, V^{LH}(P_1,P_2) = \Pi^{L*} \ and\ \mathcal{N}_d : 0 < P_1 \leq \frac{q_H P_2}{q_L}, W^{LH}(P_1,P_2) = \Pi^{L*},$$

Figure 4: Single-crossing property and constrained optimization problem for the high-quality entrepreneur when $q_L < q_H \leq \frac{(\alpha^2+6\alpha+25)q_L}{16}$ (Color Online)



(a) Single-crossing property



(b) Constrained optimization

Notes. The parameters are $q_L = 3$, $q_H = 5$, $\alpha = 0.45$ for (a) and (b).

respectively. Similarly, we let $\mathcal{S}$ denote the iso-profit curve for the high-quality entrepreneur and define $\mathcal{S}_u$ and $\mathcal{S}_d$ as

$$\mathcal{S}_u : P_2 < P_1 \leq q_H, V^H(P_1,P_2) = \Pi^{HL*} \ \textit{and} \ \mathcal{S}_d : 0 < P_1 \leq P_2, W^H(P_1,P_2) = \Pi^{HL*},$$

respectively. The following lemma shows that the iso-profit curves $\mathcal{N}_d$ and $\mathcal{S}_d$ satisfy the single-crossing property.

Lemma 5 **(Single-Crossing Property)**. *The iso-profit curves $\mathcal{N}_d$ and $\mathcal{S}_d$ intersect once at (P_2', P_1'), where $P_1' < P_2' < \frac{q_H}{2}$. When they intersect, $\mathcal{N}_d$ crosses $\mathcal{S}_d$ from below.*

Figure 4(a) illustrates the single-crossing property established in Lemma 5. It also depicts the feasible region for credible signaling $\mathbb{Q}'$. In particular, the feasible pricing region for the high-quality entrepreneur lies at the intersection area inside $\mathcal{S}_d$ and $\mathcal{S}_u$ curves and the outside area of $\mathcal{N}_d$ incorporating $P_1 \geq T$,[6] which guarantees the existence of equilibrium pricing pair for the high-quality entrepreneur. Given the piece-wise characteristic of $\Pi^{LH}(P_1, P_2)$, we analyze the feasible region and the separating equilibrium in the case of a relatively small asymmetry in quality levels (i.e., when $q_H - q_L$ is small) here. The analysis of the case with a large gap in potential quality levels is moved to Appendix B due to space limitations.

[6] We use P_2 as the horizontal axis and P_1 as the vertical axis for expositional purposes and let $\Pi^{ij}(P_2, P_1)$ denote the entrepreneur's expected profit in all figures, hereafter.

For a small gap in potential quality levels, the potential gain for the low-quality entrepreneur if he imitates the high-quality one's pricing strategy to be perceived as a high-type is not large. In such a case, for a low-quality entrepreneur, commitment to a high price in the regular selling period that drives him out of the market (i.e., $P_2 > q_L$) to mislead the funding period customers is not enticing. Therefore, the low-quality entrepreneur does not commit to high regular selling prices with $P_2 > q_L$ (i.e., the third case in (10) is excluded). In particular, we can show when $q_L < q_H \leq \frac{(\alpha^2+6\alpha+25)q_L}{16}$, no $P_2 > q_L$ is present on the iso-profit curve $\mathcal{N}$ (as shown in Figure 4(a)). The following lemma helps us characterize the separating equilibrium in this case.

LEMMA 6. *The optimal pricing pair for the high-quality entrepreneur under full information,* $(P_{1f}^{H*}, P_{2f}^{H*}) = (P_1^{H*}, P_2^{H*})$ *as characterized in Lemma 4, is located inside the iso-profit curve* $\mathcal{N}$*, i.e.,* $\Pi^{LH}(P_{1f}^{H*}, P_{2f}^{H*}) > \Pi^{L*}$*. The necessary condition must be binding in the separating equilibrium, i.e.,* $\Pi^{LH}(P_{1se}^{H}, P_{2se}^{H}) = \Pi^{L*}$*.*

Lemma 6 confirms that the equilibrium pricing pair of the high-quality entrepreneur deviates from his optimal pricing pair in the full-information case. More importantly, it indicates that we need to look for the equilibrium pricing pair for the high-quality entrepreneur on the iso-profit curve $\mathcal{N}$. To solve the high-quality entrepreneur's problem in (12)−(14), based on Lemma 6, we solve the optimization problem for pricing pairs (P_1, P_2) located on $\mathcal{N}$ (they must also satisfy the sufficient condition). Considering the piece-wise characteristics of the objective function $\Pi^H(P_1, P_2)$ and the iso-profit curve $\mathcal{N}$, we characterize the high-quality entrepreneur's problem in different regions, as Figure 4(b) depicts. For example, in region II, characterized by $P_2 \leq P_1 \leq \frac{q_H P_2}{q_L}$, the high-quality entrepreneur's optimization problem can be written as

$$\Pi^H(P_1, P_2) = V^H(P_1, P_2), \qquad s.t.\ P_2 < P_1 \leq \frac{q_H P_2}{q_L},\ W^{LH}(P_1, P_2) = \Pi^{L*}.$$

In this region, for the high-quality entrepreneur, the α-customers will purchase for sure in the separating equilibrium, so the objective function is given by $\Pi^H(P_1, P_2) = V^H(P_1, P_2)$. For the low-quality type, if he is believed to be of high quality, the α-customers will purchase with the probability $\frac{1-P_2/q_L}{1-P_1/q_H}$, so $\Pi^{LH}(P_1, P_2) = W^{LH}(P_1, P_2)$. Similarly, the objective functions and the constraints for the high-quality entrepreneur in regions I and III are listed in Table 2. Solving the constrained optimization problem above, the following proposition characterizes the separating equilibrium when $q_L < q_H \leq \frac{(\alpha^2+6\alpha+25)q_L}{16}$.

PROPOSITION 2. *Let* $(\dot{P}_1, \dot{P}_2)$ *be the solution for* P_1 *and* $P_2 > \frac{q_H}{2}$ *to* $4P_1 + (1-\alpha)P_2 = 2q_H$ *and* $W^{LH}(P_1, P_2) = \Pi^{L*}$*. For* $T \leq \dot{P}_1$*, just a unique separating equilibrium survives the*

Table 2: Objective functions and constraints for the high-quality entrepreneur

	Objective functions	Constraints
Region I	$\Pi^H(P_1,P_2)=V^H(P_1,P_2)$,	s.t. $\frac{q_H P_2}{q_L}<P_1\leq q_H$, $V^{LH}(P_1,P_2)=\Pi^{L*}$
Region II	$\Pi^H(P_1,P_2)=V^H(P_1,P_2)$,	s.t. $P_2<P_1\leq \frac{q_H P_2}{q_L}$, $W^{LH}(P_1,P_2)=\Pi^{L*}$
Region III	$\Pi^H(P_1,P_2)=W^H(P_1,P_2)$,	s.t. $0<P_1\leq P_2$, $W^{LH}(P_1,P_2)=\Pi^{L*}$

intuitive criterion refinement in which the equilibrium funding and regular selling prices are given by $(P_{1se}^H, P_{2se}^H)=(\dot{P}_1,\dot{P}_2)$, *with* $P_{1se}^H<P_{1f}^{H*}$ *and* $P_{2se}^H>P_{2f}^{H*}$. *The equilibrium pricing pair for the low-quality entrepreneur is the same as the full-information case.*

Proposition 2 indicates that when the financing needs of the project is not very large (i.e., $T\leq\dot{P}_1$), the high-quality entrepreneur can signal his type by committing to an appropriate pair of prices $(\dot{P}_1,\dot{P}_2)$, as shown in Figure 4(b). As this figure indicates, the high-quality entrepreneur manipulates both his funding and regular selling prices to separate himself from a low-quality one: The equilibrium funding price is distorted downward while the committed regular selling price is distorted upward from the full-information case. A pooling equilibrium also exists but similar to one-price signaling, we show that such an equilibrium does not survive the intuitive criterion refinement, as presented in Online Supplement D.2.

In one-price signaling, through the reference cases, we demonstrate that the probabilistic nature of crowdfunding plays a pivotal role in quality signaling. It is left to investigate the role of the probabilistic nature of crowdfunding in two-price signaling. To do so, we introduce our third reference case. Consider a setting identical to the second reference case (advance selling settings) but assume that the entrepreneur can commit to his regular selling price. Such a model is similar to the advance selling model studied by Chen and Jiang (2021) without social learning. We show that a high-quality entrepreneur can still signal his quality to customers through price commitment (Online Supplement C.3). Quality signaling when access to the second period is guaranteed indicates that the driving force of the separating equilibrium in crowdfunding settings under price commitment is not the probabilistic nature of crowdfunding anymore. Instead, as we explain next, the manipulation of both period prices to increase the opportunity cost of mimicking for a low-quality entrepreneur is at work to signal quality.

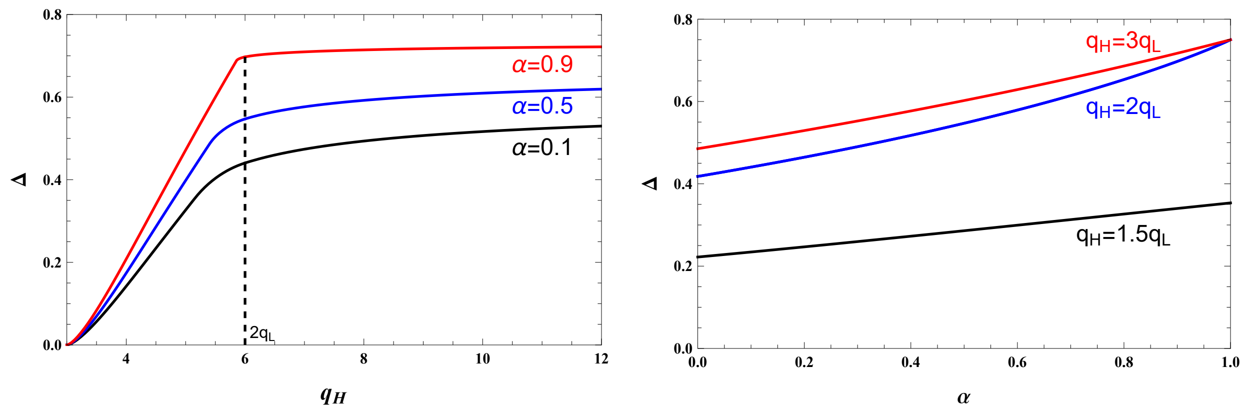
Our characterization of the separating equilibrium for the third reference model has further implications. In the third reference model, when the gap in quality levels is not large (i.e., $q_H\leq 2q_L$), the entrepreneur only needs to distort his regular selling price upward to signal his high quality. In Online Supplement C.3, we investigate the distortion in the funding and the regular selling period prices in crowdfunding settings to show that the entrepreneur has to increase the upward distortion in the regular selling period price compared to the third reference model. The probabilistic nature of crowdfunding reduces the opportunity cost of committing to a high price for a low-quality entrepreneur as he incurs the cost only if the campaign is successful. This makes the high-quality entrepreneur increase the upward distortion in his regular selling price. Unlike the third reference model, the entrepreneur also distorts his funding price downward. To see why such combined distortions in prices (i.e., an upward distortion in the regular selling period price alongside a downward distortion in the funding price) are optimal for the entrepreneur, note that a lower funding price increases the chance of reaching the regular selling period in crowdfunding settings. This increases the expected opportunity cost of committing to a high price in the second period for a low-quality entrepreneur. Such a combination of distortions in the funding and the regular selling prices minimizes the signaling cost of the high-quality entrepreneur.

The literature on quality signaling through price commitment in advance selling indicates that just the committed price in the regular selling period might be enough to signal a high-quality level (Chen and Jiang 2021). We show that the probabilistic nature of crowdfunding makes it more efficient for the high-quality entrepreneur to use both the funding and the regular selling prices to signal his high quality. In summary, the distinct feature of crowdfunding, i.e., the probabilistic nature of crowdfunding, plays different roles in one- and two-price signaling. It is the driving force for the separating equilibrium in one-price signaling. In contrast, in two-price signaling, the probabilistic nature of crowdfunding just affects how the entrepreneur should manipulate his funding and regular selling prices.

6. Numerical Experiments

One might expect an extra signaling tool, i.e., commitment to the regular selling price, improves the high-quality entrepreneur's profit in the separating equilibrium (Chen and Jiang 2021). By manipulating the funding and regular selling prices, the high-quality entrepreneur can reduce the required distortion in the funding price in one-price signaling, increasing his expected profit. Although such a projection is not surprising, the practical limitations of two-price signaling (on the credibility of price commitment) bring forward the question of when price commitment is the most beneficial to the entrepreneur. To address this question, we investigate how the degree of quality asymmetry level (i.e., the gap in quality levels) and the correlations between customers' valuations in the two selling

Figure 5: Equilibrium profit comparison between one- and two-price signaling



(a) $q_H \in (q_L, 4q_L)$ (b) $\alpha \in (0,1)$

periods affect the price commitment advantage over one-price signaling. We use numerics to investigate these questions. First, we show the following.

Proposition 3. *For the one- and two-price signaling mechanisms, $\overline{p}_1 < \dot{P}_1$; thus, the separating equilibrium under both mechanisms exists only when $T \leq \overline{p}_1$.*

Proposition 3 indicates that when the financing target is not high, the one- and two-price signaling mechanisms are plausible. Otherwise, only two-price signaling might exist, nullifying the comparison of these mechanisms. Therefore, we assume $T \leq \overline{p}_1$ in the rest of this section. Proposition 3 also addresses the question we raised on potential shortcomings of one-price signaling. Since $\overline{p}_1 < \dot{P}_1$, the price commitment can reduce the distortion in the funding price. Therefore, it allows the financing of projects with higher target levels. Figure 5 depicts how the gap in expected profits under the two- and one-price signaling mechanisms (i.e., $\Delta = \Pi^H(P^H_{1se}, P^H_{2se}) - \pi^H(p^H_{1se})$) changes as a function of the market parameters. Figure 5(a) demonstrates that the advantage of price commitment over one-price signaling increases as the degree of quality asymmetry level increases. A larger gap in potential quality levels favors signaling through price commitment. It is not difficult to show that the required distortion from the first-best funding price for a high-quality entrepreneur increases in the degree of quality asymmetry level in one-price signaling, i.e., a larger gap in potential quality levels makes mimicking more enticing for the low-quality entrepreneur, so the high-quality entrepreneur needs to increase the distortion in the funding price. In contrast to one-price signaling, an increase in potential quality levels does not need a drastic reduction in the funding price in two-price signaling because the entrepreneur can manipulate the funding and the regular selling prices. Furthermore, although Δ sharply increases for $q_L \leq q_H \leq 2q_L$, it is flat for larger gaps in potential quality levels.

Figure 5(a) also shows that a higher correlation between customers' valuations in the two selling periods increases the value of price commitment. This finding is consistent with Figure 5(b) because it depicts how the gap in profits under two- and one-price signaling changes in α. In particular, the advantage of two-price signaling increases in the correlation between customers' valuations in the two selling periods. As discussed in Section 4, a high correlation between customers' valuations in the funding and regular selling periods increases the price distortion in one-price signaling. Two-price signaling helps the entrepreneur reduce the distortion in the funding price by manipulating the regular selling price. Therefore, the advantage of the price commitment over one-price signaling is more emphasized when the required distortion in the funding price is larger, e.g., for a strong correlation between customers' tastes.

To summarize this section, our numerical investigation highlights that price commitment is the most beneficial for the entrepreneur when the degree of quality asymmetry level is high and the correlation between customers' valuations in the funding and regular selling periods is strong. If an entrepreneur believes he is facing such circumstances, our finding encourages him to pursue the two-price signaling mechanism to signal his quality.

7. Discussion and Conclusion

This paper investigates whether entrepreneurs with high-quality products can signal their quality through pricing strategies in reward-based crowdfunding campaigns. Specifically, we study two pricing mechanisms: one- and two-price signaling mechanisms. First, we demonstrate how a high-quality entrepreneur can separate himself from a low-quality entrepreneur by posting a sufficiently low funding price. This finding contrasts with existing literature on quality signaling in advance selling. The literature establishes that, in the absence of informed customers, the first-period price cannot serve as a credible quality signaling tool (Chen and Jiang 2021, Yu et al. 2015). The probabilistic nature of crowdfunding introduces an indirect effect of first-period pricing on the entrepreneur's profit, allowing the separating equilibrium to arise as the unique PBE that survives the intuitive criterion. Given that posting a low funding price to signal high quality is costly for a high-quality entrepreneur, we propose two-price signaling, where the entrepreneur also commits to his regular selling price at the beginning of the funding period. We show that high-quality entrepreneurs can signal their type through price commitment and reduce signaling costs. We investigate the driving forces of these signaling mechanisms and demonstrated that distinct drivers are involved in these signaling mechanisms.

In the presented model, several simplifying assumptions are made. In particular, we assume that customers in the funding period are homogeneous. This assumption simplifies the modeling of campaign success probability in the funding period for tractability purposes. We also assume that the only source of information on customers' tastes in the regular selling period is the observed campaign in the first period. After successful delivery, it is quite plausible that customer feedback conveys information on customers' tastes in the regular selling period. In Online Supplement E, we comment on the robustness of our findings by introducing a model that incorporates the heterogeneity of customers in the funding period and market updating for the entrepreneur.

We would like to highlight potential avenues for future research. In this study, we overlook the potential strategic behavior of customers in the funding period. Some customers may defer their purchases in the hope of lower prices in the regular selling period after a successful funding campaign. Modeling the effect of such behavior on crowdfunding design is an interesting pursuit because the strategic behavior of customers in crowdfunding has remained largely unstudied. Similarly, how an entrepreneur can use his crowdfunding campaign design as a marketing research tool to uncover the potential market size or valuation of customers in the regular selling period is worthy of investigation.

Finally, we believe that incorporating the regular selling period into crowdfunding models can significantly affect crowdfunding campaign design. However, this area appears to have been untapped by researchers. Although this study demonstrates the importance of the regular selling period for quality signaling, more questions need to be answered. For example, the moral hazard issue in reward-based crowdfunding, studied by Strausz (2017) can be alleviated through regular selling price commitment. The effect of regular selling periods on crowdfunding campaign design is a promising research topic.

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Table 3: Table of Notation

α	Proportion of the regular selling period customers that share the same taste as the funding period customers
T	Crowdfunding financing target level
q_i (q_j)	True (Believed) quality levels of the product, $i, j = \{H, L\}$
p_1, p_2	Funding and regular selling prices without price commitment
(P_1, P_2)	Pricing pair with price commitment
θ_c	Product taste of the funding period customers
$\theta_{r\alpha}$, θ_{rc}	Product taste of the two groups of customers in the regular selling period
$\tilde{\theta}_{r\alpha}$	Updated product taste for α-customers in the regular selling period
$a, a'(\cdot)$	Pre- and post-belief of customers about the product quality
$\pi^{ij}(p_1)$ $\Pi^{ij}(P_1, P_2)$	Expected profit of the entrepreneur with true quality q_i and believed as q_j without/with price commitment
p_1^{ij*}, (P_1^{ij*}, P_2^{ij*})	Optimal price(s) for $\pi^{ij}(p_1)$ and $\Pi^{ij}(P_1, P_2)$
p_{1se}^i, (P_{1se}^i, P_{2se}^i)	Separating equilibrium price(s) in one-price (two-price) signaling
p_{1f}^i, (P_{1f}^i, P_{2f}^i)	Optimal price(s) for the entrepreneur under full-information case without/with price commitment
$\pi_2^{ij}(p_2 \mid T \leq p_1 \leq q_j)$	Expected regular selling profit of the entrepreneur with true quality q_i and believed as q_j without price commitment, given $T \leq p_1 \leq q_j$
$\overline{p}_1, \overline{p}_1'$	Thresholds on the funding price with $\pi^{L*} = \pi^{LH}(\overline{p}_1) = \pi^{LH}(\overline{p}_1')$ and $T \leq \overline{p}_1 < p_1^{L*} < \overline{p}_1'$ in one-price signaling
$\underline{p}_1, \underline{p}_1'$	Threshold on the funding price with $\pi^{HL*} = \pi^{H}(\underline{p}_1) = \pi^{H}(\underline{p}_1')$ and $T \leq \underline{p}_1 < p_1^{HL*} < \underline{p}_1'$ in one-price signaling
(P_1', P_2'), (P_1'', P_2''), $P_1' < P_1''$	Intersection points of the two iso-profit curves $\mathcal{N}$ and $\mathcal{S}$
$(\dot{P}_1, \dot{P}_2)$	Solution for $P_1 < \frac{q_H}{2}$ to $4P_1 + (1-\alpha)P_2 = 2q_H$ and $W^{LH}(P_1, P_2) = \Pi^{L*}$

Appendix to "Quality Signaling through Crowdfunding Pricing"

Appendix A: Proofs of Main Results

Proof of Lemma 1 It is straightforward to show that when $0 < p_2 < \frac{p_1 q_i}{q_j}$, $\pi_2^{ij}(p_2) = \alpha p_2 + (1-\alpha)(1 - \frac{p_2}{q_i})p_2$ is maximized at $p_2 = \frac{q_i}{2(1-\alpha)} \wedge \frac{p_1 q_i}{q_j}$; when $\frac{p_1 q_i}{q_j} \leq p_2 \leq q_i$, $\pi_2^{ij}(p_2) = \frac{\alpha}{1 - p_1/q_j}(1 - \frac{p_2}{q_i})p_2 + (1-\alpha)(1 - \frac{p_2}{q_i})p_2$ is maximized at $p_2 = (\frac{q_i}{2} \vee \frac{p_1 q_i}{q_j}) \wedge q_i$.

When $\frac{q_i T}{q_j} \leq \frac{p_1 q_i}{q_j} < \frac{q_i}{2}$, i.e., $T \leq p_1 < \frac{q_j}{2}$, $\pi_2^{ij}(p_2)$ first increases in $p_2 \in [0, \frac{q_i}{2}]$, then decreases, so $p_2^{ij*} = \frac{q_i}{2}$. When $\frac{q_i}{2} \leq \frac{p_1 q_i}{q_j} < \frac{q_i}{2(1-\alpha)} \wedge q_i$, i.e., $\frac{q_j}{2} \leq p_1 < \frac{q_j}{2(1-\alpha)} \wedge q_j$, $\pi_2^{ij}(p_2)$ first increases in $p_2 \in [0, \frac{p_1 q_i}{q_j}]$, then decreases, so $p_2^{ij*} = \frac{p_1 q_i}{q_j}$. When $\frac{q_i}{2(1-\alpha)} \wedge q_i \leq \frac{p_1 q_i}{q_j} \leq q_i$, i.e., $\frac{q_j}{2(1-\alpha)} \wedge q_j \leq p_1 \leq q_j$, $\pi_2^{ij}(p_2)$ first increases in $p_2 \in [0, \frac{q_i}{2(1-\alpha)}]$, then decreases, so $p_2^{ij*} = \frac{q_i}{2(1-\alpha)}$.

When $T \geq \frac{q_j}{2}$, only the range of $\frac{p_1 q_i}{q_j}$ changes since $p_1 \geq T$, due to the campaign success condition. Therefore, the optimality of $\pi_2^{ij}(p_2)$ does not change, and we can get the optimal regular selling price p_2^{ij*} accordingly. By plugging p_2^{ij*} into $\pi_2^{ij}(p_2)$, we can get the corresponding optimal expected profit of the entrepreneur in the regular selling period. $\square$

Proof of Lemma 2 We show $\pi^{ij}(p_1)$ is uni-modal in p_1 when $T < \frac{4q_j-(1-\alpha)q_i}{8}$, and the uni-modality when $T \geq \frac{4q_j-(1-\alpha)q_i}{8}$ can be proved similarly.

It is straightforward to check that when $p_1 \in [T, \frac{q_j}{2})$, $\pi^{ij}(p_1) = (1-\frac{p_1}{q_j})(p_1 + (\frac{\alpha}{1-p_1/q_j} + (1-\alpha))\frac{q_i}{4})$ is concave in p_1, as the second order derivative is negative, and it is maximzed at $p_1^{ij*} = \frac{4q_j-(1-\alpha)q_i}{8} < \frac{q_j}{2}$. Therefore, $\pi^{ij}(p_1)$ first increases in $[T, \frac{4q_j-(1-\alpha)q_i}{8})$ and then decreases in $[\frac{4q_j-(1-\alpha)q_i}{8}, \frac{q_j}{2})$.

Next we show when $p_1 \in [\frac{q_j}{2}, \frac{q_j}{2(1-\alpha)})$, $\pi^{ij}(p_1) = (1-\frac{p_1}{q_j})(p_1 + \frac{\alpha p_1 q_i}{q_j} + (1-\alpha)(1-\frac{p_1}{q_j})\frac{p_1 q_i}{q_j})$ decreases in p_1. First, note that the second order derivative $\frac{d^2\pi^{ij}(p_1)}{dp_1^2} < 0$, because $\frac{d^3\pi^{ij}(p_1)}{dp_1^3} = \frac{6(1-\alpha)q_i}{q_j^3} > 0$ and $\frac{d^2\pi^{ij}(p_1)}{dp_1^2}|_{p_1=\frac{q_j}{2(1-\alpha)}} = -\frac{(1-2\alpha)q_i+2q_j}{q_j^2} < 0$ (note that $\frac{q_j}{2(1-\alpha)} \leq q_j$). Similarly, $\frac{d\pi^{ij}(p_1)}{dp_1} < 0$, as $\frac{d\pi^{ij}(p_1)}{dp_1}|_{p_1=\frac{q_j}{2}} = \frac{(\alpha-1)q_i}{4q_j} < 0$. Therefore, $\pi^{ij}(p_1)$ decreases in $p_1 \in [\frac{q_j}{2}, \frac{q_j}{2(1-\alpha)})$.

Finally, for $p_1 \in [\frac{q_j}{2(1-\alpha)}, p_j]$ (note this case only exists when $0<\alpha<\frac{1}{2}$), it is straightforward to check that $\pi^{ij}(p_1) = (1-\frac{p_1}{q_j})(p_1 + \frac{\alpha q_i}{2(1-\alpha)} + (1-\frac{1}{2(1-\alpha)})\frac{q_i}{2})$ is concave in p_1 and is maximized at $\frac{1}{8}(4q_j - \frac{q_i}{1-\alpha}) < \frac{q_j}{2(1-\alpha)}$, therefore, $\pi^{ij}(p_1)$ decreases in $p_1 \in [\frac{q_j}{2(1-\alpha)}, p_j]$.

Based on the above discussion, $\pi^{ij}(p_1)$ is uni-modular in p_1 when $T < \frac{4q_j-(1-\alpha)q_i}{8}$, as it first increases and then decreases in p_1, and is maximized at $p_1^{ij*} = \frac{4q_j-(1-\alpha)q_i}{8}$. When $T \geq \frac{4q_j-(1-\alpha)q_i}{8}$, only the range of p_1 shrinks but the form of $\pi^{ij}(p_1)$ does not change, so the uni-modality is maintained and the optimal funding price becomes financing target level. $\square$

Proof of Lemma 3 We first prove the lemma when $T \leq \underline{p}_1$, as shown in Figure 3(a). In this case, $p_1^{HL*} = \frac{4q_L-(1-\alpha)q_H}{8}$ and $p_1^{L*} = \frac{(3+\alpha)q_L}{8}$. From the definitions of $\pi^{LH}(p_1)$, p_1^{LH*} and π^{L*}, it is straightforward to see $\pi^{LH}(p_1^{LH*}) > \pi^{LH}(p_1^{L*}) > \pi^{L}(p_1^{L*})$. Given that $\pi^{LH}(p_1)$ is uni-modal in p_1, there exists a unique $\overline{p}_1 < p_1^{L*}$ that satisfies $\pi^{LH}(\overline{p}_1) = \pi^{L*}$, and a unique $\overline{p}_1' > p_1^{LH*} > p_1^{L*}$ that satisfies $\pi^{LH}(\overline{p}_1') = \pi^{L*}$. A similar argument shows that there exist $\underline{p}_1 < p_1^{HL*} < p_1^{H*} < \underline{p}_1'$ that satisfy $\pi^{HL*} = \pi^{H}(\underline{p}_1) = \pi^{H}(\underline{p}_1')$.

To prove $\overline{p}_1 > \underline{p}_1$ and $\overline{p}_1' > \underline{p}_1'$, we first transform $\pi^{ij}(p_1)$ when $T \leq p_1 < \frac{q_j}{2}$ as follows,

$$\begin{aligned}\pi^{ij}(p_1) &= (1-\tfrac{p_1}{q_j})(p_1 + (\tfrac{\alpha}{1-p_1/q_j} + (1-\alpha))\tfrac{q_i}{4}) = (1-\tfrac{p_1}{q_j})(p_1 + (1-\alpha)\tfrac{q_i}{4}) + \tfrac{\alpha}{4}q_i \\ &= \int_{p_1/q_j}^{1} \big(2\theta q_j - (q_j - (1-\alpha)\tfrac{q_i}{4})\big) f(\theta)\, d\theta + \tfrac{\alpha}{4}q_i, \end{aligned} \tag{A.1}$$

where θ is a random parameter and $\theta \sim U[0,1]$. In what follows, we show $\overline{p}_1 > \underline{p}_1$ by contradiction. Suppose $\overline{p}_1 \leq \underline{p}_1$, then we have,

$$\begin{aligned}&\pi^{H}(\underline{p}_1) - \pi^{LH}(\overline{p}_1) \\ &= \int_{\underline{p}_1/q_H}^{1} \big(2\theta q_H - (q_H - (1-\alpha)\tfrac{q_H}{4})\big) f(\theta)\, d\theta + \tfrac{\alpha}{4}q_H - \left(\int_{\overline{p}_1/q_H}^{1} \big(2\theta q_H - (q_H - (1-\alpha)\tfrac{q_L}{4})\big) f(\theta)\, d\theta + \tfrac{\alpha}{4}q_L\right) \\ &= \int_{\underline{p}_1/q_H}^{1} \tfrac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta - \int_{\overline{p}_1/q_H}^{\underline{p}_1/q_H} \big(2\theta q_H - (q_H - (1-\alpha)\tfrac{q_L}{4})\big) f(\theta)\, d\theta + \tfrac{\alpha}{4}(q_H - q_L) \\ &> \int_{\underline{p}_1/q_H}^{1} \tfrac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta + \tfrac{\alpha}{4}(q_H - q_L).\end{aligned}$$

The inequality holds because $\overline{p}_1 \leq \underline{p}_1$ and $\underline{p}_1/q_H < p_1^{LH*}/q_H = \frac{q_H-(1-\alpha)q_L/4}{2q_H}$. Further, we can obtain

$$\begin{aligned}&\pi^{HL}(p_1^{HL*}) - \pi^{L}(p_1^{L*}) \\ &= \int_{p_1^{HL*}/q_L}^{1} \big(2\theta q_L - (q_L - (1-\alpha)\tfrac{q_H}{4})\big) f(\theta)\, d\theta + \tfrac{\alpha}{4}q_H - \left(\int_{p_1^{L*}/q_L}^{1} \big(2\theta q_L - (q_L - (1-\alpha)\tfrac{q_L}{4})\big) f(\theta)\, d\theta + \tfrac{\alpha}{4}q_L\right)\end{aligned}$$

$$
\begin{aligned}
&= \int_{p_1^{HL*}/q_L}^{1} \tfrac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta + \int_{p_1^{HL*}/q_L}^{p_1^{L*}/q_L} \left(2\theta q_L - (q_L - (1-\alpha)\tfrac{q_L}{4})\right) f(\theta)\, d\theta + \tfrac{\alpha}{4}(q_H - q_L) \\
&< \int_{p_1^{HL*}/q_L}^{1} \tfrac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta + \tfrac{\alpha}{4}(q_H - q_L).
\end{aligned}
$$

The inequality holds since $p_1^{L*}/q_L > p_1^{HL*}/q_L$ and $p_1^{L*}/q_L = \frac{q_L-(1-\alpha)q_L/4}{2q_L}$.

Notice that $\int_{\underline{p}_1/q_H}^{1} \frac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta > \int_{p_1^{HL*}/q_L}^{1} \frac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta$, since $\underline{p}_1 < p_1^{HL*}$. Consequently, the above two inequalities lead to $\pi^{HL}(p_1^{HL*}) - \pi^{L}(p_1^{L*}) < \pi^{H}(\underline{p}_1) - \pi^{LH}(\overline{p}_1)$, which contradicts the definitions that $\pi^{H}(\underline{p}_1) = \pi^{HL}(p_1^{HL*})$ and $\pi^{LH}(\overline{p}_1) = \pi^{L}(p_1^{L*})$. Hence, we must have $\overline{p}_1 > \underline{p}_1$.

Next, we show $\overline{p}_1' > \underline{p}_1'$. Because of the piece-wise characteristics of $\pi^{ij}(p_1)$, we first show the property when $\overline{p}_1'$ and $\underline{p}_1'$ are in the same range of the cases in the piece-wise function, respectively, and then we show it still holds if $\overline{p}_1'$ and $\underline{p}_1'$ are in different ranges.

i) When $\overline{p}_1', \underline{p}_1' < \frac{q_H}{2}$, $\pi^{H}(p_1)$ and $\pi^{LH}(p_1)$ could still be represented in the form of (A.1), and we show $\overline{p}_1' > \underline{p}_1'$ by contradiction. Suppose $\overline{p}_1' \le \underline{p}_1'$, then we have

$$
\begin{aligned}
&\pi^{H}(\underline{p}_1') - \pi^{LH}(\overline{p}_1') \\
&= \int_{\underline{p}_1'/q_H}^{1} \left(2\theta q_H - (q_H - (1-\alpha)\tfrac{q_H}{4})\right) f(\theta)\, d\theta + \tfrac{\alpha}{4} q_H - \left(\int_{\overline{p}_1'/q_H}^{1} \left(2\theta q_H - (q_H - (1-\alpha)\tfrac{q_L}{4})\right) f(\theta)\, d\theta + \tfrac{\alpha}{4} q_L \right) \\
&= \int_{\overline{p}_1'/q_H}^{1} \tfrac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta + \int_{\underline{p}_1'/q_H}^{\overline{p}_1'/q_H} \left(2\theta q_H - (q_H - (1-\alpha)\tfrac{q_H}{4})\right) f(\theta)\, d\theta + \tfrac{\alpha}{4}(q_H - q_L) \\
&< \int_{\overline{p}_1'/q_H}^{1} \tfrac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta + \tfrac{\alpha}{4}(q_H - q_L). \qquad \text{(A.2)}
\end{aligned}
$$

The inequality holds because we assume $\underline{p}_1' \ge \overline{p}_1'$ and $\overline{p}_1'/q_H > p_1^{H*}/q_H = \frac{q_H-(1-\alpha)q_H/4}{2q_H}$.

$$
\begin{aligned}
&\pi^{HL}(p_1^{HL*}) - \pi^{L}(p_1^{L*}) \\
&= \int_{p_1^{HL*}/q_L}^{1} \left(2\theta q_L - (q_L - (1-\alpha)\tfrac{q_H}{4})\right) f(\theta)\, d\theta + \tfrac{\alpha}{4} q_H - \left(\int_{p_1^{L*}/q_L}^{1} \left(2\theta q_L - (q_L - (1-\alpha)\tfrac{q_L}{4})\right) f(\theta)\, d\theta + \tfrac{\alpha}{4} q_L \right) \\
&= \int_{p_1^{L*}/q_L}^{1} \tfrac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta + \int_{p_1^{HL*}/q_L}^{p_1^{L*}/q_L} \left(2\theta q_L - (q_L - (1-\alpha)\tfrac{q_H}{4})\right) f(\theta)\, d\theta + \tfrac{\alpha}{4}(q_H - q_L) \\
&> \int_{p_1^{L*}/q_L}^{1} \tfrac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta + \tfrac{\alpha}{4}(q_H - q_L). \qquad \text{(A.3)}
\end{aligned}
$$

The inequality holds as $p_1^{L*}/q_L > p_1^{HL*}/q_L$ and $p_1^{HL*}/q_L = \frac{q_L-(1-\alpha)q_H/4}{2q_L}$.

Note that $p_1^{L*}/q_L - \overline{p}_1'/q_H = \frac{-(q_H-q_L)(1-\alpha)-\sqrt{(q_H-q_L)(16q_H-(1-\alpha)^2 q_L)}}{8q_H} < 0$, so $\int_{p_1^{L*}/q_L}^{1} \frac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta > \int_{\overline{p}_1'/q_H}^{1} \frac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta$. Consequently, the above two inequalities lead to $\pi^{HL}(p_1^{HL*}) - \pi^{L}(p_1^{L*}) > \pi^{H}(\underline{p}_1') - \pi^{LH}(\overline{p}_1')$, which contradicts the definitions that $\pi^{H}(\underline{p}_1') = \pi^{HL}(p_1^{HL*})$ and $\pi^{LH}(\overline{p}_1') = \pi^{L}(p_1^{L*})$. Hence, we conclude that $\underline{p}_1' < \overline{p}_1'$.

ii) When $\frac{q_H}{2} \le \overline{p}_1', \underline{p}_1' \le \frac{q_H}{2(1-\alpha)}$, we transform $\pi^{ij}(p_1)$ to the following,

$$
\begin{aligned}
\pi^{ij}(p_1) &= (1 - \tfrac{p_1}{q_j})(p_1 + \tfrac{\alpha p_1 q_i}{q_j} + (1-\alpha)(1 - \tfrac{p_1}{q_j})\tfrac{p_1 q_i}{q_j}) \\
&= \int_{p_1/q_j}^{1} \left(-3(1-\alpha) q_i \theta^2 + 2(q_j + 2(1-\alpha) q_i)\theta - (q_i + q_j)\right) f(\theta)\, d\theta.
\end{aligned}
$$

Therefore, we have

$$
\begin{aligned}
&\pi^H(\underline{p}_1') - \pi^{LH}(\overline{p}_1') \\
&= \int_{\underline{p}_1'/q_H}^1 \left(-3(1-\alpha)q_H\theta^2 + 2(3-\alpha)q_H\theta - 2q_H\right) f(\theta)\, d\theta - \int_{\overline{p}_1'/q_H}^1 \left(-3(1-\alpha)q_L\theta^2 + 2(q_H + 2(1-\alpha)q_L)\theta - (q_H+q_L)\right) f(\theta)\, d\theta \\
&= \int_{\overline{p}_1'/q_H}^1 (q_H - q_L)(3(\alpha-1)\theta^2 + 2(2-\alpha)\theta - 1) f(\theta)\, d\theta + \int_{\underline{p}_1'/q_H}^{\overline{p}_1'/q_H} \left(-3(1-\alpha)q_H\theta^2 + 2(3-\alpha)q_H\theta - 2q_H\right) f(\theta)\, d\theta \\
&< \int_{\overline{p}_1'/q_H}^1 (q_H - q_L)(3(\alpha-1)\theta^2 + 2(2-\alpha)\theta - 1) f(\theta)\, d\theta, \qquad \text{(A.4)}
\end{aligned}
$$

where the inequality hold as we assume $\overline{p}_1' \le \underline{p}_1'$ and $-3(1-\alpha)q_H\theta^2 + 2(3-\alpha)q_H\theta - 2q_H > 0$ for $\theta \in [\frac{1}{2}, \frac{1}{2(1-\alpha)}]$. Equation (A.4) can further be transformed as,

$$
\begin{aligned}
&\int_{\overline{p}_1'/q_H}^1 (q_H - q_L)(3(\alpha-1)\theta^2 + 2(2-\alpha)\theta - 1) f(\theta)\, d\theta = (q_H - q_L)\left(\tfrac{\overline{p}_1'}{q_H} - (2-\alpha)(\tfrac{\overline{p}_1'}{q_H})^2 - (\alpha-1)(\tfrac{\overline{p}_1'}{q_H})^3\right) \\
&< (q_H - q_L)\left(\tfrac{1}{4} - \tfrac{1-\alpha}{4}\tfrac{\overline{p}_1'}{q_H}\right) = \int_{\overline{p}_1'/q_H}^1 \tfrac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta + \tfrac{\alpha}{4}(q_H - q_L),
\end{aligned}
$$

where the inequality holds as $\frac{1}{4} - \frac{1-\alpha}{4}\frac{\overline{p}_1'}{q_H} - \frac{\overline{p}_1'}{q_H} + (2-\alpha)(\frac{\overline{p}_1'}{q_H})^2 + (\alpha-1)(\frac{\overline{p}_1'}{q_H})^3$ increases in $\overline{p}_1' \in [\frac{q_H}{2}, \frac{q_H}{2(1-\alpha)}]$, and equal to 0 when $\overline{p}_1' = \frac{q_H}{2}$.

Since $\overline{p}_1' \ge \frac{q_H}{2}$ in this case, and $p_1^{L*} = \frac{(3+\alpha)q_L}{8}$, so $\overline{p}_1'/q_H > p_1^{L*}/q_L$. Therefore, simialr to the case (i), we get $\pi^{HL}(p_1^{HL*}) - \pi^L(p_1^{L*}) > \pi^H(\underline{p}_1') - \pi^{LH}(\overline{p}_1')$, which contradicts the definitions that $\pi^H(\underline{p}_1') = \pi^{HL}(p_1^{HL*})$ and $\pi^{LH}(\overline{p}_1') = \pi^L(p_1^{L*})$. Hence, we conclude that $\underline{p}_1' < \overline{p}_1'$ when $\frac{q_H}{2} \le \overline{p}_1', \underline{p}_1' \le \frac{q_H}{2(1-\alpha)}$.

iii) When $\frac{q_H}{2(1-\alpha)} < \overline{p}_1', \underline{p}_1'$, the proof is quite similar as we transform $\pi^{ij}(p_1)$ as follows,

$$
\pi^{ij}(p_1) = (1 - \tfrac{p_1}{q_j})(p_1 + \tfrac{\alpha q_i}{2(1-\alpha)} + (1 - \tfrac{1}{2(1-\alpha)})\tfrac{q_i}{2}) = \int_{\frac{p_1}{q_j}}^1 \left(2\theta q_j - q_j + \tfrac{\alpha q_i}{2(1-\alpha)} + (1 - \tfrac{1}{2(1-\alpha)})\tfrac{q_i}{2}\right) f(\theta)\, d\theta.
$$

Based on the above discussion, $\overline{p}_1' > \underline{p}_1'$ holds when $\overline{p}_1'$ and $\underline{p}_1'$ are in the same range of the piece-wise profit function. Next, note that

$$
\begin{aligned}
&(\pi^{HL*} - \pi^H(\tfrac{q_H}{2})) - (\pi^{L*} - \pi^{LH}(\tfrac{q_H}{2})) = \tfrac{(q_H^2 - q_L^2)(1-\alpha)^2}{64 q_L} > 0, \\
&(\pi^{HL*} - \pi^H(\tfrac{q_H}{2(1-\alpha)})) - (\pi^{L*} - \pi^{LH}(\tfrac{q_H}{2(1-\alpha)})) = \tfrac{(q_H - q_L)((\alpha^2 + 6\alpha + 1)q_L + (1-\alpha)^2 q_H)}{64 q_L} > 0,
\end{aligned}
$$

i.e., $\pi^{HL*} > \pi^H(\frac{q_H}{2})$ when $\pi^{L*} \ge \pi^{LH}(\frac{q_H}{2})$, and $\pi^{HL*} > \pi^H(\frac{q_H}{2(1-\alpha)})$ when $\pi^{L*} \ge \pi^{LH}(\frac{q_H}{2(1-\alpha)})$. Therefore, when $\overline{p}_1' < \frac{q_H}{2}$, $\underline{p}_1'$ must be less than $\frac{q_H}{2}$, and when $\overline{p}_1' < \frac{q_H}{2(1-\alpha)}$, $\underline{p}_1'$ must be less than $\frac{q_H}{2(1-\alpha)}$, which demonstrates that $\overline{p}_1' > \underline{p}_1'$, in general.

Now consider the case of $T > \underline{p}_1$. Our findings can be extended to $\underline{p}_1 < T \le \frac{4q_L - (1-\alpha)q_H}{8}$ (to show that $\overline{p}_1' > \underline{p}_1'$), as $p_1^{HL*} = \frac{4q_L - (1-\alpha)q_H}{8}$ and $p_1^{L*} = \frac{(3+\alpha)q_L}{8}$ still hold when $T \le \frac{4q_L - (1-\alpha)q_H}{8}$ and the form of the piece-wise function $\pi^{ij}(p_1)$ does not change with the increase of T. Then we prove $\overline{p}_1' > \underline{p}_1'$ when $T > \frac{4q_L - (1-\alpha)q_H}{8}$. We first prove the case when $T > \frac{(3+\alpha)q_L}{8}$ (the case in Figure 3(b)), where $p_1^{HL*} = p_1^{L*} = T$; the case $\frac{4q_L - (1-\alpha)q_H}{8} < T \le \frac{(3+\alpha)q_L}{8}$ can be proved similarly. We show $\overline{p}_1' > \underline{p}_1'$ when $T > \frac{(3+\alpha)q_L}{8}$ in the following case, and other cases can be proved similarly.

When $\frac{(3+\alpha)q_L}{8} < T < \frac{q_L}{2}$ and $\overline{p}_1', \underline{p}_1' < \frac{q_H}{2}$, we show $\overline{p}_1' > \underline{p}_1'$ by contradiction. Suppose $\overline{p}_1' \le \underline{p}_1'$. Similar formulation as (A.2), and (A.3) can be transformed to the following form,

$$
\begin{aligned}
&\pi^{HL}(T) - \pi^L(T) = \int_{T/q_L}^1 \left(2\theta q_L - (q_L - (1-\alpha)\tfrac{q_H}{4})\right) f(\theta)\, d\theta + \tfrac{\alpha}{4} q_H - \left(\int_{T/q_L}^1 \left(2\theta q_L - (q_L - (1-\alpha)\tfrac{q_L}{4})\right) f(\theta)\, d\theta + \tfrac{\alpha}{4} q_L\right) \\
&= \int_{T/q_L}^1 \tfrac{1-\alpha}{4}(q_H - q_L) f(\theta)\, d\theta + \tfrac{\alpha}{4}(q_H - q_L). \qquad \text{(A.5)}
\end{aligned}
$$

Note that $\overline{p}_1' = \frac{4q_Hq_L+\sqrt{q_L((4q_H-(1-\alpha)q_L)^2q_L-16q_HT(-4T+(3+\alpha)q_L))}-(1-\alpha)q_L^2}{8q_L}$ in this case, and $T/q_L - \overline{p}_1'/q_H < 0$. Therefore $\int_{T/q_L}^1 \frac{1-\alpha}{4}(q_H-q_L)f(\theta)\,d\theta + \frac{\alpha}{4}(q_H-q_L) > \int_{\overline{p}_1'/q_H}^1 \frac{1-\alpha}{4}(q_H-q_L)f(\theta)\,d\theta + \frac{\alpha}{4}(q_H-q_L)$. Consequently, the above two inequalities lead to $\pi^{HL}(T) - \pi^L(T) > \pi^H(\underline{p}_1') - \pi^{LH}(\overline{p}_1')$, which contradicts the definitions that $\pi^H(\underline{p}_1') = \pi^{HL}(T)$ and $\pi^{LH}(\overline{p}_1') = \pi^L(T)$. $\square$

Proof of Proposition 1 Based on Lemma 3, when $T \leq \overline{p}_1$, it is clear that if funding period customers hold a belief as

$$j(p_1) = \begin{cases} H & \text{if } p_1 = \overline{p}_1, \\ L & \text{otherwise,} \end{cases}$$

where $\overline{p}_1$ is defined as in Lemma 3, then the entrepreneur's equilibrium funding price is given by

$$p_{1se}^i = \begin{cases} \overline{p}_1 & \text{if } i = H, \\ p_1^{L*} & \text{if } i = L. \end{cases}$$

That is, under this belief structure, when the entrepreneur is of low quality, he sets the funding price at p_1^{L*} and has no incentive to set his price at $\overline{p}_1$ to mimic the high-quality entrepreneur's strategy; the entrepreneur also has no incentive to deviate from $\overline{p}_1$ if he is of high quality. The funding period customers' belief is consistent with the entrepreneur's pricing strategies. Thus, a separating equilibrium exists and we can show that this is the unique equilibrium that survives the intuitive criterion in the Online Supplement D.1.

When $T > \overline{p}_1$, the financing needs of the project makes the high-quality entrepreneur set $p_1 \in [T, \underline{p}_1']$, and the low quality entrepreneur will always imitate him. Therefore, only the pooling equilibrium exists. $\square$

Proof of Lemma 4 In the proof, we first ignore the effect of the financing target level T and assume $P_1 \in [0, q_j]$. The profit function of the entrepreneur in this case is as follows,

$$\tilde{\Pi}^{ij}(P_1, P_2) = \begin{cases} (1-\frac{P_1}{q_j})(P_1 + \alpha P_2 + (1-\alpha)(1-\frac{P_2}{q_i})P_2) & \frac{q_jP_2}{q_i} \leq P_1 \leq q_j \\ (1-\frac{P_1}{q_j})(P_1 + \frac{\alpha}{1-P_1/q_j}(1-\frac{P_2}{q_i})P_2 + (1-\alpha)(1-\frac{P_2}{q_i})P_2) & 0 \leq P_1 < \frac{q_jP_2}{q_i} \end{cases} \quad \text{(A.6)}$$

It is straightforward to verify that $V^{ij}(P_1, P_2) = (1-\frac{P_1}{q_j})(P_1 + \alpha P_2 + (1-\alpha)(1-\frac{P_2}{q_i})P_2)$ is jointly concave in (P_1, P_2) and is globally maximized at $(\frac{4(1-\alpha)q_j - q_i}{8(1-\alpha)}, \frac{q_i}{2(1-\alpha)})$, and similarly, $W^{ij}(P_1, P_2) = (1-\frac{P_1}{q_j})(P_1 + \frac{\alpha}{1-P_1/q_j}(1-\frac{P_2}{q_i})P_2 + (1-\alpha)(1-\frac{P_2}{q_i})P_2)$ is jointly concave in (P_1, P_2) and is globally maximized at $(\frac{4q_j-(1-\alpha)q_i}{8}, \frac{q_i}{2})$. Next we incorporate the constraints on the range of P_1 given in (A.6).

When $\frac{q_jP_2}{q_i} \leq P_1 \leq q_j$, $V^{ij}(P_1, P_2)$ is maximized at $P_2^* = \frac{q_i}{2(1-\alpha)}$ independent of P_1. We prove the case of $0 < \alpha \leq \frac{1}{2}$, i.e., $\frac{q_j}{2(1-\alpha)} \leq q_j$ in what follows; the case of $\frac{1}{2} < \alpha < 1$ can be proved similarly.

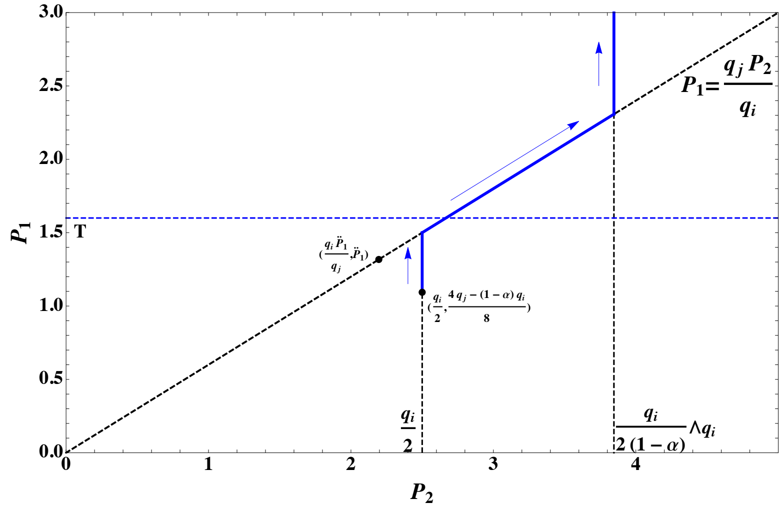
When $\frac{q_jP_2}{q_i} \leq P_1 \leq \frac{q_j}{2(1-\alpha)}$, then $\frac{q_i}{2(1-\alpha)} \geq \frac{P_1q_i}{q_j} \geq P_2$, so $P_2^* = \frac{P_1q_i}{q_j}$. $V^{ij}(P_1, \frac{P_1q_i}{q_j})$ is concave in P_1 and is maximized at

$$\ddot{P}_1 = \frac{q_j}{3q_i(1-\alpha)}\left(q_j + (2-\alpha)q_i - \sqrt{q_j^2 + (\alpha+1)q_iq_j + (\alpha^2-\alpha+1)q_i^2}\right) < \frac{q_j}{2} < \frac{q_j}{2(1-\alpha)}.$$

When $\frac{q_j}{2(1-\alpha)} < P_1 \leq q_j$, then $\frac{q_i}{2(1-\alpha)} < \frac{P_1q_i}{q_j}$, therefore, $P_2^* = \frac{q_i}{2(1-\alpha)}$, and $V^{ij}(P_1, \frac{q_i}{2(1-\alpha)})$ decreases in $P_1 \in (\frac{q_j}{2(1-\alpha)}, q_j]$. Comparing $V^{ij}(P_1, \frac{q_i}{2(1-\alpha)})$ and $V^{ij}(P_1, \frac{P_1q_i}{q_j})$, it is straightforward to check that $\tilde{\Pi}^{ij}(P_1, P_2)$ is maximized at $(\ddot{P}_1, \frac{\ddot{P}_1q_i}{q_j})$ when $0 \leq P_2 \leq \frac{P_1q_i}{q_j}$.

When $0 \leq P_1 < \frac{q_jP_2}{q_i}$, $W^{ij}(P_1, P_2)$ is maximized at $P_2^* = \frac{q_i}{2}$ for any given P_1. For $0 < P_1 \leq \frac{q_j}{2}$, $\frac{q_i}{2} > \frac{P_1q_i}{q_j}$, so $P_2^* = \frac{q_i}{2}$, and $W^{ij}(P_1, \frac{q_i}{2})$ is concave in P_1 and $P_1^* = \frac{1}{8}(4q_j + (-1+\alpha)q_i) < \frac{q_j}{2}$. For $\frac{q_j}{2} < P_1 < q_j$, $\frac{q_i}{2} < \frac{P_1q_i}{q_j}$, so $P_2^* = \frac{P_1q_i}{q_j}$. As $W^{ij}(P_1, \frac{P_1q_i}{q_j})$ decreases in P_1, it is maximized at $P_1 = \frac{q_j}{2}$ and $P_2 = \frac{q_i}{2}$. It is straightforward to

Figure A.1: Optimal (P_1, P_2) for $\Pi^{ij}(P_1, P_2)$



show that for $0 \leq P_1 < \frac{q_j P_2}{q_i}$, $\tilde{\Pi}^{ij}(P_1, P_2)$ is maximized at $(\frac{4q_j+(-1+\alpha)q_i}{8}, \frac{q_i}{2})$. Figure A.1 demonstrates both of the constrained optimal pricing pairs $(\ddot{P}_1, \frac{\ddot{P}_1 q_i}{q_j})$ and $(\frac{4q_j+(-1+\alpha)q_i}{8}, \frac{q_i}{2})$. Finally, we can compare the optimal expected profits for $\frac{q_j P_2}{q_i} \leq P_1 < q_j$ and $0 \leq P_1 < \frac{q_j P_2}{q_i}$, to show the global optimal pricing pair is given by $(\frac{4q_j+(-1+\alpha)q_i}{8}, \frac{q_i}{2})$.

Next, we incorporate the financing target level T. Clearly, for small and moderate financing target levels i.e., $T \leq \frac{4q_j+(-1+\alpha)q_i}{8}$, the optimal funding price is given by $\frac{4q_j+(-1+\alpha)q_i}{8}$. For $T > \frac{4q_j+(-1+\alpha)q_i}{8}$, the optimal funding price is equal to the minimum financing needs, T. A higher level of funding price reveals information on the valuation of α-customers in the regular selling period that affects the price in the regular selling period. Similar to our proof for Lemma 2, we can show that the optimal price in the regular selling period lies on the blue path highlighted in Figure A.1 as T increases from $\frac{4q_j+(-1+\alpha)q_i}{8}$. $\square$

Proof of Lemma 5 We first show the two iso-profit curves $\mathcal{N}$ and $\mathcal{S}$ intersect. As (P_1^{H*}, P_2^{H*}) is the global maximizer for $\Pi^H(P_1, P_2)$, therefore (P_1^{H*}, P_2^{H*}) must satisfy the constraint $\Pi^H(P_1^{H*}, P_2^{H*}) \geq \Pi^{HL*}$, and it lies inside the iso-profit curve $\mathcal{S}$. As it is shown in Lemma 6, (P_1^{H*}, P_2^{H*}) also lies inside the iso-profit curve $\mathcal{N}$. Therefore, there exists an overlapping region that lies inside both of the iso-profit curve $\mathcal{N}$ and $\mathcal{S}$, so (P_1', P_2') and (P_1'', P_2'') exist.

Next, we show (P_1', P_2') that satisfies $P_1' < P_2' < \frac{q_H}{2}$ exists by investigate the intersection of two iso-profit curves, $W^{LH}(P_1, P_2) = \Pi^{L*}$ and $W^H(P_1, P_2) = \Pi^{HL*}$ (without constraint $P_1 \geq T$). Define

$$F(x,y,z) = (1 - \tfrac{x}{q_H})\left(x + \tfrac{\alpha}{1-x/q_H}(1-\tfrac{y}{z})y + (1-\alpha)(1-\tfrac{y}{z})y\right) - \tfrac{(4q_L+(1-\alpha)z)^2+16\alpha z q_L}{64 q_L}. \tag{A.7}$$

Then $F(P_1, P_2, q_L) = 0$ is the iso-profit curve of $W^{LH}(P_1, P_2) = \Pi^{L*}$ and $F(P_1, P_2, q_H) = 0$ is the iso-profit curve of $W^H(P_1, P_2) = \Pi^{HL*}$. We can find the partial derivative of x with respect to y for (x, y)s on the curve $F(x, y, z) = 0$ as

$$\tfrac{\partial x}{\partial y} = -\tfrac{F_y}{F_x} = \tfrac{(2y-z)(q_H-(1-\alpha)x)}{(q_H-2x)z+(1-\alpha)(y-z)y}. \tag{A.8}$$

Based on (A.8), for the (x, y) on the curve $F(x, y, z) = 0$ with $x \leq \frac{q_H z+(1-\alpha)(y-z)y}{2z}$, x first decreases in y, and then increases in y. When $y = \frac{z}{2}$, x is the smallest; when $(q_H - 2x)z + (1-\alpha)(y-z)y = 0$, (x, y) is the extreme point on the left (or on the right) on the curve $F(x,y,z)=0$, as it is shown in Figure A.2. When $y=x$, we have

$$\frac{\partial x}{\partial z} = -\frac{F_z}{F_x} > 0^7, \tag{A.9}$$

Based on (A.9), the intersection of $x=y$ and $F(x,y,q_H)=0$ is larger than the intersection of $x=y$ and $F(x,y,q_L)=0$. When $y=\frac{q_H}{2}$, x that satisfies $F(x,\frac{q_H}{2},q_H)=0$ is smaller than the x in $F(x,\frac{q_H}{2},q_L)=0^8$. Therefore, there must exist at least one intersection of the two curves. We then show (P_1',P_2') is the only intersection of these two iso-profit curves when $x \le \frac{q_H z+(1-\alpha)(y-z)y}{2z}$ by contradiction. Assume the two curves cross at two distinct points (x_1,y_1) and (x_2,y_2) with $y_1<y_2$. By definition of the function, we get

$$(1-\tfrac{x_1}{q_H})\left(x_1+\tfrac{\alpha}{1-x_1/q_H}(1-\tfrac{y_1}{q_L})y_1+(1-\alpha)(1-\tfrac{y_1}{q_L})y_1\right) = (1-\tfrac{x_2}{q_H})\left(x_2+\tfrac{\alpha}{1-x_2/q_H}(1-\tfrac{y_2}{q_L})y_2+(1-\alpha)(1-\tfrac{y_2}{q_L})y_2\right) \tag{A.10}$$

$$(1-\tfrac{x_1}{q_H})\left(x_1+\tfrac{\alpha}{1-x_1/q_H}(1-\tfrac{y_1}{q_H})y_1+(1-\alpha)(1-\tfrac{y_1}{q_H})y_1\right) = (1-\tfrac{x_2}{q_H})\left(x_2+\tfrac{\alpha}{1-x_2/q_H}(1-\tfrac{y_2}{q_H})y_2+(1-\alpha)(1-\tfrac{y_2}{q_H})y_2\right) \tag{A.11}$$

Subtracting (A.11) from (A.10), we get,

$$\left(1-(1-\alpha)\tfrac{x_1}{q_H}\right)y_1^2 = \left(1-(1-\alpha)\tfrac{x_2}{q_H}\right)y_2^2.$$

Let $f(x,y)=\left(1-(1-\alpha)\frac{x}{q_H}\right)y^2$, and we have

$$\frac{\partial f(x,y)}{\partial y} = \left(1-(1-\alpha)\tfrac{x}{q_H}\right)2y-(1-\alpha)\tfrac{y^2}{q_H}\tfrac{\partial x}{\partial y}$$

As (x_1,y_1) and (x_2,y_2) both are on the curve $F(x,y,z)=0$, we know from equation (A.8) that $\frac{\partial x}{\partial y} = \frac{(2y-z)(q_H-(1-\alpha)x)}{(q_H-2x)z+(1-\alpha)(y-z)y}$, so

$$\frac{\partial f(x,y)}{\partial y} = (1-\tfrac{(1-\alpha)x}{q_H})y\tfrac{(2q_H-4x-(1-\alpha)y)z}{y(1-\alpha)(y-z)+(q_H-2x)z} > 0,$$

which implies that $f(x,y)$ monotonically increases in y. We immediately have $y_1=y_2$ and $x_1=x_2$. However, this contradicts the assumption that (x_1,y_1) and (x_2,y_2) are two distinct points, thus $F(x,y,q_H)=0$ and $F(x,y,q_L)=0$ intersect at most once when $0 \le x \le \frac{q_H z+(1-\alpha)(y-z)y}{2z}$. Therefore, the intersection (P_1',P_2') satisfying $P_1'<P_2'<\frac{q_H}{2}$, is the only intersection of the two curves below $2q_H-4P_1-(1-\alpha)P_2=0$. Moreover, $F(P_1',P_2',q_L)=0$ crosses $F(P_1',P_2',q_H)=0$ from below, because the difference of the first order derivatives is,

$$\left.\frac{\partial x}{\partial y}\right|_{z=q_H} - \left.\frac{\partial x}{\partial y}\right|_{z=q_L} = \frac{-(q_H-q_L)P_2'(q_H-(1-\alpha)P_1')(2q_H-4P_1'-(1-\alpha)P_2')}{\left(q_H^2+(1-\alpha)P_2'^2-(2P_1'+(1-\alpha)P_2')q_H\right)\left(q_Hq_L+(1-\alpha)P_2'^2-(2P_1'+(1-\alpha)P_2')q_L\right)} < 0 \tag{A.12}$$

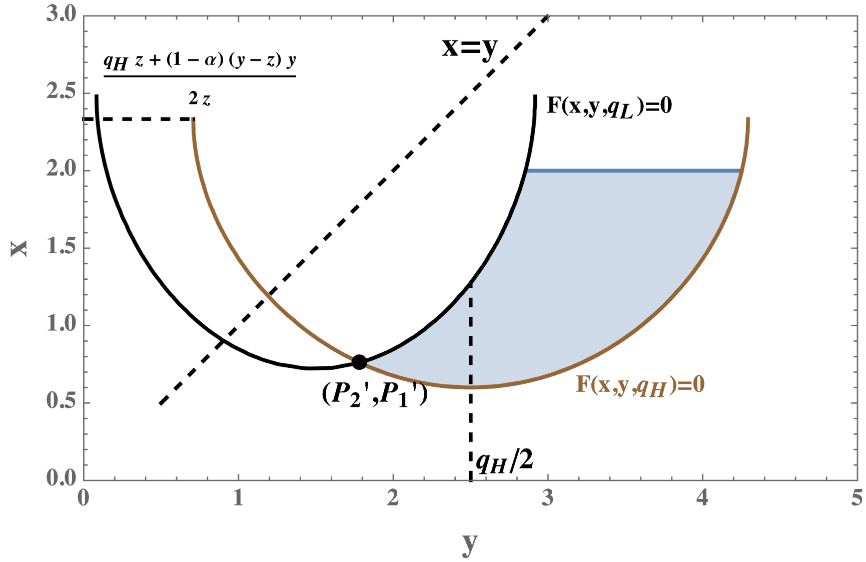
Based on the discussion above, the iso-profit curves $\mathcal{N}_d$ (i.e., $F(P_1,P_2,q_L)=0$ with $0<P_1\le\frac{q_HP_2}{q_L}$) and $\mathcal{S}_d$ (i.e., $F(P_1,P_2,q_H)=0$ with $0<P_1\le P_2$) intersect once at (P_2',P_1'), where $P_1'<P_2'<\frac{q_H}{2}$; when they intersect, it is $\mathcal{N}_d$ that crosses $\mathcal{S}_d$ from below. □

Proof of Lemma 6 Since (P_1^{H*},P_2^{H*}) and (P_1^{L*},P_2^{L*}) are characterized in Lemma 4, $\Pi^{LH}(P_{1f}^{H*},P_{2f}^{H*}) > \Pi^{L*}$ can be simply established by plugging the optimal prices into the profit functions, thus ommitted. As discussed in the proof of Lemma 4, $\Pi^{ij}(P_1,P_2)$ decreases when (P_1,P_2) deviates from the global maximizer $(P_1^{H*},P_2^{H*})=(\frac{q_H}{2},\frac{(3+\alpha)q_H}{8})$ (without the financing constraint). Therefore, for any (P_1,P_2) that $\Pi^{LH}(P_1,P_2)<\Pi^{L*}$, there always exists a pricing pair on the iso-profit curve $\Pi^{LH}(P_1,P_2)=\Pi^{L*}$ that performs better, so the necessary condition must be binding in a separating equilibrium. □

[7] $F_x = \frac{(q_H-2x)z+(1-\alpha)(x-z)x-(2x-z)(q_H-(1-\alpha)x)}{q_Hz} > 0$, $F_z = \frac{(q_H-(1-\alpha)x)x^2}{q_Hz^2} - \frac{(1-\alpha)^2z+4(1+\alpha)q_L}{32q_L} < \frac{1+\alpha}{8} - \frac{1+\alpha}{8} = 0$.

[8] If there are two solutions for x in $F(x,\frac{q_H}{2},q_H)=0$ or $F(x,\frac{q_H}{2},q_L)=0$, the smaller one is selected.

Figure A.2: Intersection of $F(x,y,q_L)=0$ and $F(x,y,q_H)=0$



Proof of Proposition 2 First we investigate the following constrained optimization problem.

$$\max_{P_1,P_2} W^H(P_1,P_2)=(1-\tfrac{P_1}{q_H})\left(P_1+\tfrac{\alpha}{1-P_1/q_H}(1-\tfrac{P_2}{q_H})P_2+(1-\alpha)(1-\tfrac{P_2}{q_H})P_2\right) \tag{A.13}$$

$$s.t.\ W^{LH}(P_1,P_2)=(1-\tfrac{P_1}{q_H})\left(P_1+\tfrac{\alpha}{1-P_1/q_H}(1-\tfrac{P_2}{q_L})P_2+(1-\alpha)(1-\tfrac{P_2}{q_L})P_2\right)=\Pi^{L*}. \tag{A.14}$$

Based on the constraint in (A.14), we have $\frac{\partial P_2}{\partial P_1}=\frac{(1-\alpha)P_2(P_2-q_L)-(2P_1-q_H)q_L}{(2P_2-q_L)(q_H-(1-\alpha)P_1)}$, so the first order partial derivative of $W^H(P_1,P_2)$ given in (A.13) with respect to P_1 is

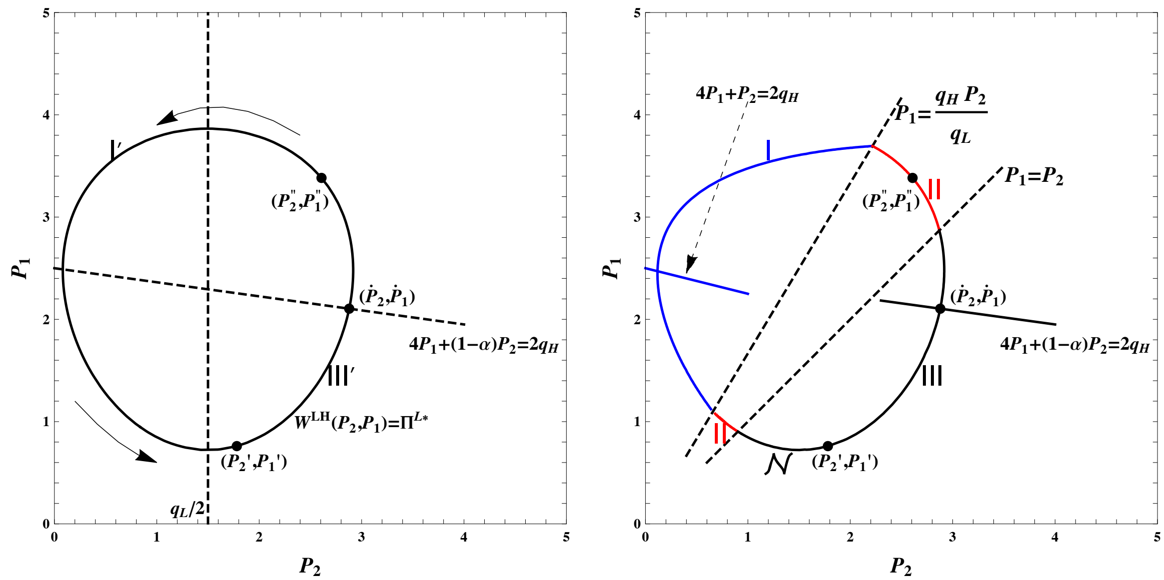
$$\begin{aligned}\frac{\partial W^H(P_1,P_2)}{\partial P_1}=&(1-\tfrac{2P_1}{q_H})+\alpha(1-\frac{2P_2}{q_H})\tfrac{\partial P_2}{\partial P_1}-(1-\alpha)(1-\tfrac{P_2}{q_H})P_2/q_H+(1-\alpha)(1-\tfrac{P_1}{q_H})(1-\tfrac{2P_2}{q_H})\tfrac{\partial P_2}{\partial P_1}\\ =&\tfrac{P_2(q_H-q_L)(4P_1+(1-\alpha)P_2-2q_H)}{(q_L-2P_2)q_H^2}.\end{aligned} \tag{A.15}$$

Denote the pricing pair (P_1,P_2) which is the solution to the following two equations,

$$4P_1+(1-\alpha)P_2=2q_H \text{ and } W^{LH}(P_1,P_2)=\Pi^{L*},$$

with $P_2>\frac{q_H}{2}>\frac{q_L}{2}$ as $(\dot{P}_1,\dot{P}_2)$, as shown in Figure A.3(a). Next, we show that $W^H(P_1,P_2)$ increases in (P_1,P_2) moving counter-clockwise on the iso-profit curve $W^{LH}(P_1,P_2)=\Pi^{L*}$ when $4P_1+(1-\alpha)P_2<2q_H$, and decreases in (P_1,P_2) moving counterclockwise on the iso-profit curve when $4P_1+(1-\alpha)P_2\geq 2q_H$, i.e., $(\dot{P}_1,\dot{P}_2)$ is the unique maximizer for the problem in (A.13)$-$(A.14). As discussed after equation (A.8) in the Proof of Lemma 5, both the maximum and the minimum P_1 that lie on this iso-profit curve happen at $P_2=\frac{q_L}{2}$. For (P_1,P_2) on the northwest of the curve (Region I' as shown in Figure A.3(a)), $4P_1+(1-\alpha)P_2\geq 2q_H$ and $P_2\leq\frac{q_L}{2}$, then based on (A.15), $W^H(P_1,P_2)$ increases in P_1. Since the counterclockwise move of (P_1,P_2) in this region indicates a reduction in P_1, then $W^H(P_1,P_2)$ decreases when (P_1,P_2) move counterclockwise. Now consider (P_1,P_2) on the sourtheast of the curve (Region III'). In this region, P_1 increases when (P_1,P_2) move counterclockwise. Since $4P_1+(1-\alpha)P_2\leq 2q_H$ and $P_2\geq\frac{q_L}{2}$, $\frac{\partial W^H(P_1,P_2)}{\partial P_1}>0$ and $W^H(P_1,P_2)$ increases when (P_1,P_2) move counterclockwise. Similarly, we can investigate the other regions, to establish the above claim. Next, we study the constrained optimization problem given in Table 2 for different regions in what follows.

Figure A.3: Illustration of the constrained optimization problem



(a) (b)

In Region III, as shown in Figure A.3(b), the entrepreneur's problem can be written as,

$$\max_{P_1,P_2} \Pi^H(P_1,P_2) = W^H(P_1,P_2), \ s.t. \ W^{LH}(P_1,P_2) = \Pi^{L*}, P_1 \leq P_2.$$

As discussed above, $(\dot{P}_1, \dot{P}_2)$ is the unique optimal pricing pair for $\Pi^H(P_1,P_2)$ on the iso-profit curve $W^{LH}(P_1,P_2) = \Pi^{L*}$. Since $W^H(P_1,P_2)$ increases in (P_1,P_2) moving counterclockwise on the iso-profit curve when $4P_1 + (1-\alpha)P_2 \leq 2q_H$, $W^H(\dot{P}_1,\dot{P}_2) > \Pi^H(P_1',P_2') = \Pi^{HL*}$, therefore, $(\dot{P}_1,\dot{P}_2)$ satisfies the sufficient condition and lies inside $\mathcal{S}$. Finally, since $\dot{P}_2 > \frac{q_H}{2}$ and $\dot{P}_1 < \frac{(3+\alpha)q_H}{8}$, $(\dot{P}_1,\dot{P}_2)$ must lie below the line $P_1 = P_2$. Therefore, $(\dot{P}_1,\dot{P}_2)$ lies in Region III.

In Region II, the entrepreneur's problem can be written as,

$$\max_{P_1,P_2} \Pi^H(P_1,P_2) = V^H(P_1,P_2), \ s.t. \ W^{LH}(P_1,P_2) = \Pi^{L*}, P_2 < P_1 \leq \frac{q_H P_2}{q_L}.$$

For $P_1 > P_2$, $\frac{\alpha}{1-P_1/q_H}(1-\frac{P_2}{q_H})P_2 > \alpha P_2$, so for any (P_1,P_2) in Region II, $V^H(P_1,P_2)$ is dominated by $W^H(P_1,P_2)$, which in turn is dominated by $W^H(\dot{P}_1,\dot{P}_2)$ in Region III (please notice that the counterclockwise property of $W^H(P_1,P_2)$ proved above, is true on all three regions). Therefore, $(\dot{P}_1,\dot{P}_2)$ is the unique optimal pricing pair for the entrepreneur for $0 < P_1 \leq \frac{q_H P_2}{q_L}$.

Finally, in Region I, the entrepreneur's problem can be written as

$$\max_{P_1,P_2} \Pi^H(P_1,P_2) = V^H(P_1,P_2), \ s.t. \ V^{LH}(P_1,P_2) = \Pi^{L*}, \frac{q_H P_2}{q_L} < P_1 \leq q_H.$$

Following a similar method to the above, we can show in this region, $V^H(P_1,P_2)$ first decreases in (P_1,P_2) moving counterclockwise on the iso-profit curve $V^{LH}(P_1,P_2) = \Pi^{L*}$, and then increases. The unique minimizing pricing pair is the solution to

$$4P_1 + P_2 - 2q_H = 0 \text{ and } V^{LH}(P_1,P_2) = \Pi^{L*}.$$

As a result, the global optimal pricing pair that maximizes $\Pi^H(P_1,P_2)$ cannot lie in Region I.

Based on the above discussion, when $T \le \dot{P}_1$, assume that the funding period customers hold a belief as

$$j(P_1,P_2)=\begin{cases} H & \text{if } (P_1,P_2)=(\dot{P}_1,\dot{P}_2), \\ L & \text{otherwise,} \end{cases}$$

and the entrepreneur's equilibrium pricing pair is given by,

$$(P^i_{1se},P^i_{2se})=\begin{cases} (\dot{P}_1,\dot{P}_2) & \text{if } i=H, \\ (P_1^{L*},P_2^{L*}) & \text{if } i=L. \end{cases}$$

It is clear that the entrepreneur's pricing pair is consistent with such a belief structure, and similar to the proof of Proposition 1, there is no profitable unilateral deviation for either types of entrepreneurs. Thus, a separating equilibrium exists; we can show the characterized separating equilibrium is the unique equilibrium that survives the intuitive criterion in the Online Supplement D.2. □

Proof of Proposition 3 Based on our demonstrations in the one- and two-price signaling cases, the $\overline{p}_1$ and $(\dot{P}_1,\dot{P}_2)$ satisfy

$$(1-\tfrac{\overline{p}_1}{q_H})(\overline{p}_1+(\tfrac{\alpha}{1-\overline{p}_1/q_H}+(1-\alpha))\tfrac{q_L}{4})=\pi^{L*}, \tag{A.16}$$

and

$$4\dot{P}_1+(1-\alpha)\dot{P}_2=2q_H, \tag{A.17}$$

$$(1-\tfrac{\dot{P}_1}{q_H})\left(\dot{P}_1+\tfrac{\alpha}{1-\dot{P}_1/q_H}(1-\tfrac{\dot{P}_2}{q_L})\dot{P}_2+(1-\alpha)(1-\tfrac{\dot{P}_2}{q_L})\dot{P}_2\right)=\Pi^{L*}, \tag{A.18}$$

respectively, where $\dot{P}_2>\frac{q_H}{2}$, $\dot{P}_1<\frac{(3+\alpha)q_H}{8}$ and $\pi^{L*}=\Pi^{L*}$. Based on (A.17), $\dot{P}_2=\frac{2(q_H-2\dot{P}_1)}{1-\alpha}$, therefore

$$(1-\tfrac{\dot{P}_2}{q_L})\dot{P}_2-\tfrac{q_L}{4}=-\tfrac{(8\dot{P}_1-q_H+(1-\alpha)q_L)^2}{4(1-\alpha)^2q_L}<0$$

Let $M(x,y)=(1-\frac{x}{q_H})(x+(\frac{\alpha}{1-x/q_H}+(1-\alpha))y)-\pi^{L*}$, then $M(\overline{p}_1,\frac{q_L}{4})=0$ is the equation in (A.16), and $M(\dot{P}_1,(1-\frac{\dot{P}_2}{q_L})\dot{P}_2)=0$ is the equation in (A.18). Because $x,y<q_H$ and $\overline{p}_1<\frac{(3+\alpha)q_L}{8}$,

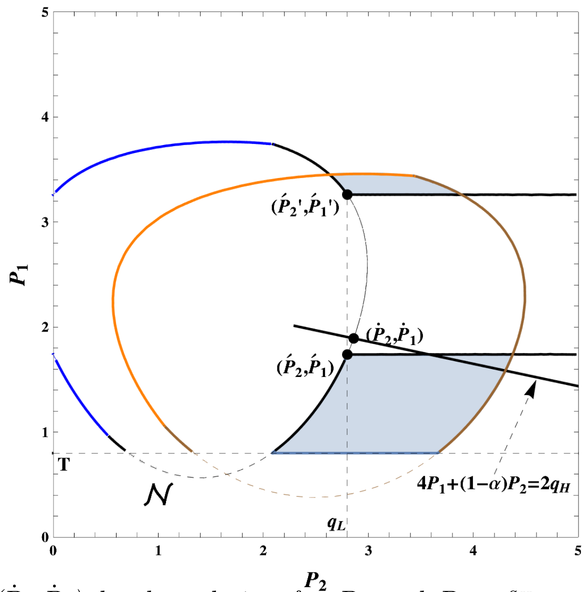
$$\tfrac{\partial x}{\partial y}=-\tfrac{M_y}{M_x}=\tfrac{(1-\alpha)x-q_H}{q_H-2x-(1-\alpha)y}<0,$$

so $\dot{P}_1>\overline{p}_1$. □

Appendix B: Signaling through price commitment for large degree of quality asymmetry

When the potential gap between the high and low product quality is relatively large, a low-quality entrepreneur has a stronger incentive to mimic the high-quality one's pricing strategy to make the funding period customers believe he is of high quality. Therefore, to reduce the low-quality entrepreneurs' incentive to mimic his pricing strategy, the high-quality entrepreneur might commit to a high regular selling price that drives the low-quality one out of the regular selling period market. In particular, when $q_H>\frac{(\alpha^2+6\alpha+25)q_L}{16}$, there exists $P_2\ge q_L$ on the iso-profit curve $\mathcal{N}$. Let $\acute{P}_1$ and $\acute{P}_1'$ ($\acute{P}_1<\acute{P}_1'$) denote the solutions for P_1 to $W^{LH}(P_1,q_L)=\Pi^{L*}$ and $V^{LH}(P_1,q_L)=\Pi^{L*}$, respectively. Since the profit function $\Pi^{LH}(P_1,P_2)$ is not a function of P_2 when $P_2>q_L$, the iso-profit curve $\mathcal{N}$ becomes parallel to the P_2 axis, as shown in Figure B.1. The single-crossing property of the iso-profit cureves still holds and the following proposition characterizes the separating equilibrium in this case.

Figure B.1: Illustration of the separating equilibrium for large degree of quality asymmetry level (color online)



Proposition B.1. *Let* $(\dot{P}_1, \dot{P}_2)$ *be the solution for* P_1 *and* $P_2 > \frac{q_H}{2}$ *to* $4P_1 + (1-\alpha)P_2 = 2q_H$ *and* $W^{LH}(P_1, P_2) = \Pi^{L*}$. *For* $T \leq \dot{P}_1 \wedge \acute{P}_1$, *there exists a unique separating equilibrium that survives the intuitive criterion refinement, and*

$$(P^H_{1se}, P^H_{2se}) = \begin{cases} (\acute{P}_1, q_H/2) & q_H \geq 2q_L, \\ (\dot{P}_1 \wedge \acute{P}_1, \min\{\dot{P}_2, q_L\}) & \frac{(\alpha^2+6\alpha+25)q_L}{16} < q_H < 2q_L. \end{cases} \tag{B.1}$$

where $\acute{P}_2$ *is the solution to* $W^{LH}(P^H_{1se}, P_2) = \Pi^{L*}$. *The pricing pair for the low-quality entrepreneur is the same as the pricing pair under the full-information case.*

Proposition B.1 shows that a separating equilibrium still exists in this case. In particular, the characterized separating equilibrium is the unique equilibrium that survives the intuitive criterion. For large gaps in quality levels, i.e., $q_H \geq 2q_L$, the optimal regular selling price for the high-quality entrepreneur is already large enough that it excludes any mimicking low-quality entrepreneurs from the regular selling market (i.e., $P^H_{2se} = q_H/2 \geq q_L$). In the separating equilibrium, it is enough for the funding price to satisfy $\Pi^{LH}(P_{1se}, q_H/2) = \Pi^{LH}(P_{1se}, q_L) = \Pi^{L*}$. This is in line with the findings in the advance selling literature (Chen and Jiang 2021) as it predicts distortion in the funding price happens only in the case of large gaps in potential quality levels. Any upward distortion in the second period price does not have any effect on a mimicking low-quality entrepreneur to prevent his imitation. Therefore, the entrepreneur has to reduce his funding price to prevent mimicking. For relatively large gaps in potential quality levels, i.e., $\frac{(\alpha^2+6\alpha+25)q_L}{16} < q_H < 2q_L$, the entrepreneur might still need to manipulate both prices to prevent mimicking by the low-quality one. Figure C.3 in the Online Supplement C.3 depicts the above findings.

Online Supplements to "Quality Signaling through Crowdfunding Pricing"

Appendix C: Reference models

In this section, we study the reference models for both of the introduced signaling mechanisms.

C.1. One-period crowdfunding

In this model, we characterize the equilibrium funding price of the entrepreneur in the absence of the regular selling period. If there is no regular selling period, the expected profit of the entrepreneur with product quality q_i when he is believed to be of quality q_j is given by

$$\pi^{ij}(p_1) = (1 - p_1/q_j)p_1, i, j = \{H, L\}.$$

It is straightforward to check that $\pi^H(p_1) = \pi^{LH}(p_1)$ and $\pi^L(p_1) = \pi^{HL}(p_1)$. Therefore, the feasible range for the high-quality entrepreneur that satisfies the following necessary and sufficient conditions, i.e.,

$$\pi^{LH}(p_1) \le \pi^{L*}, and\ \pi^H(p_1) \ge \pi^{HL*},$$

is given by just two points, $\underline{\underline{p}}_1$ and $\overline{\overline{p}}_1'$, as shown in Figure C.1(a). When $p_{1se}^H = \underline{\underline{p}}_1$ or $\overline{\overline{p}}_1'$, the expected profits of these two types are the same as $\pi^H(p_{1se}^H) = \pi^L(p_{1se}^L) = \pi^{L*}$, i.e., the separating equilibria are degenerate as they result in the same profit as the low-quality entrepreneur. Under a pooling equilibrium, the profit functions for these two types of entrepreneur are given by

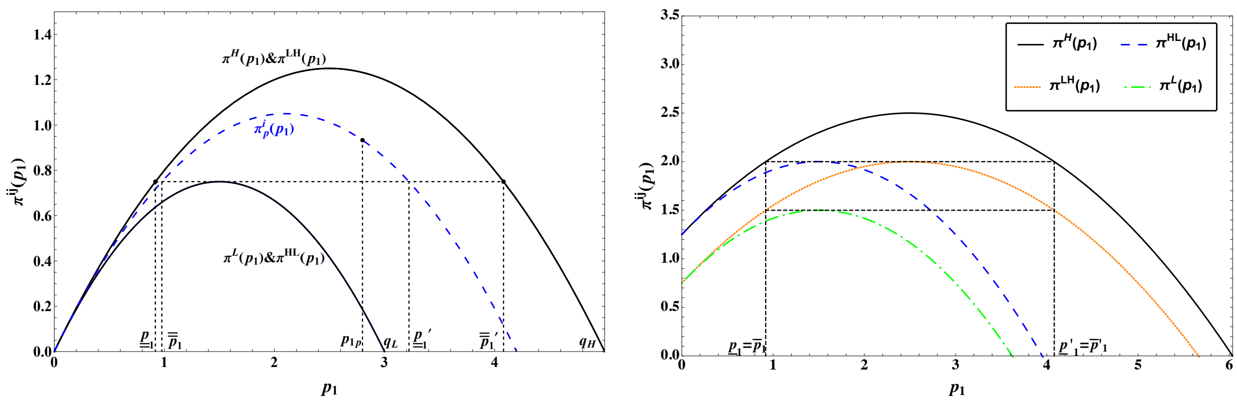
$$\pi_P^H(p_1) = \pi_P^L(p_1) = (1 - \tfrac{p_1}{q_P})p_1,$$

where q_P is the expected perceived quality and the subscript P stands for the pooling equilibrium. $q_P = aq_H + (1-a)q_L$ and $q_L < q_P < q_H$. Define $\overline{\overline{p}}_1$ and $\underline{\underline{p}}_1'$ that satisfy $\pi_P^i(\overline{\overline{p}}_1) = \pi_P^i(\underline{\underline{p}}_1') = \pi^{L*}$. It is straightforward to show that $\overline{\overline{p}}_1 > \underline{\underline{p}}_1$ and $\underline{\underline{p}}_1' < \overline{\overline{p}}_1'$. When $p_1 \in [\overline{\overline{p}}_1, \underline{\underline{p}}_1']$, $\pi_P^i(p_1) \ge \pi^{L*}$, i.e., the profits of both types of the entrepreneur under pooling equilibrium is greater than their profits under the separating equilibrium when $\overline{\overline{p}}_1 \le p_{1P} \le \underline{\underline{p}}_1'$. It is straightforward to show that the pooling equilibrium price lies in this range; therefore, the pooling equilibrium arises as the Pareto dominant PBE equilibrium. In addition, the pooling equilibrium is clearly the unique PBE that survives the lexicographically maximum sequential equilibrium (LMSE) refinement introduced by Mailath et al. (1993) since $\pi_P^H > \pi^H(\underline{\underline{p}}_1)$. Moreover, the pooling equilibrium survives the intuitive criterion as there does not exist a belief off the equilibrium path under which a high-type is better-off than a mimicking low-type (note that $\pi^H(p_1) = \pi^{LH}(p_1)$).

C.2. Advance selling

In this subsection, we study the entrepreneur's problem in an advance selling setting, where the regular selling period is not contingent on a successful campaign in the first period. We solve this problem by backward induction; first, we derive the optimal regular selling price of the entrepreneur after a successful or failed campaign. When $p_2 \ge \frac{p_1 q_i}{q_j}$, α-customers would purchase with probability $\frac{1-p_2/q_i}{1-p_1/q_j}$ if the campaign succeeds, and they would not purchase for sure if the campaign fails. When $0 < p_2 < \frac{p_1 q_i}{q_j}$, α-customers would purchase for sure if the campaign succeeds, and they would purchase with probability $(\frac{p_1}{q_j} - \frac{p_2}{q_i})/(\frac{p_1}{q_j})$ if the

Figure C.1: Illustration of profit functions for the entrepreneur in reference models (color online)



(a) The first reference case (b) The second reference case

campaign fails. For the common customers in regular selling period, their product taste remains the same as $\theta_{rc} \sim U[0,1]$, and the expected profit is given by $(1-\alpha)(1-\frac{p_2}{q_i})p_2$. Therefore, the expected profit function of the entrepreneur in the regular selling period is

$$
\begin{aligned}
\pi_2^{ij}(p_2) &= \begin{cases} (1-\frac{p_1}{q_j})\left(\alpha\frac{1-p_2/q_i}{1-p_1/q_j}p_2+(1-\alpha)(1-\frac{p_2}{q_i})p_2\right)+\frac{p_1}{q_j}(1-\alpha)(1-\frac{p_2}{q_i})p_2 & \frac{p_1q_i}{q_j}\le p_2\le q_i, \\ (1-\frac{p_1}{q_j})\left(\alpha p_2+(1-\alpha)(1-\frac{p_2}{q_i})p_2\right)+\frac{p_1}{q_j}\left(\alpha p_2(\frac{p_1}{q_j}-\frac{p_2}{q_i})/(\frac{p_1}{q_j})+(1-\alpha)(1-\frac{p_2}{q_i})p_2\right) & 0<p_2<\frac{p_1q_i}{q_j}, \end{cases} \\
&= \begin{cases} (1-\frac{p_2}{q_i})p_2 & \frac{p_1q_i}{q_j}\le p_2\le q_i, \\ (1-\frac{p_2}{q_i})p_2 & 0<p_2<\frac{p_1q_i}{q_j}, \end{cases} \\
&= (1-\frac{p_2}{q_i})p_2, 0<p_2\le q_i.
\end{aligned}
$$

The entrepreneur can update the taste distribution for α-customers and sell to customers in the regular selling period even after a failed campaign. The optimal price in the regular selling period is $p_2^{ij*}=\frac{q_i}{2}$, and the expected profit of the entrepreneur in the regular selling period is $\pi_2^{ij}=\frac{q_i}{4}$. The expected profit in the funding period is $(1-\frac{p_1}{q_j})p_1$ if the funding period customers believe the product quality is q_j. Therefore, the expected profit for the entrepreneur at the beginning of the funding period is given by

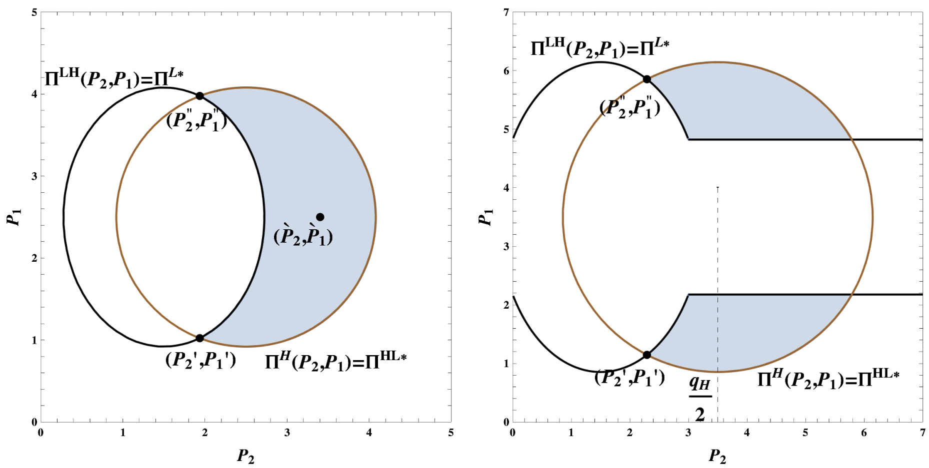
$$\pi^{ij}(p_1)=(1-\frac{p_1}{q_j})p_1+\frac{q_i}{4}.$$

The profit curves for $i,j=\{H,L\}$ is illustrated in Figure C.1(b). It is straight forward to show that $\underline{p}_1=\overline{p}_1$ and $\underline{p}_1'=\overline{p}_1'$, where $\pi^H(\underline{p}_1)=\pi^H(\underline{p}_1')=\pi^{HL}(p_1^{HL*})$ and $\pi^{LH}(\overline{p}_1)=\pi^{LH}(\overline{p}_1')=\pi^L(p_1^{L*})$. Similar to Chen and Jiang (2021), we can show that the pooling equilibrium is the unique PBE that survives the LMSE refinement. Moreover, similar to the first reference model we can show that the pooling equilibrium survives the intuitive criterion refinement since for any funding price p_1, $\pi^H(p_1)=\pi^{LH}(p_1)+(q_H-q_L)/4$, i.e, the gap in expected profit of a high-type and a mimicking low-type is independent of the funding price.

C.3. Advance selling with price commitment

In the third reference model, we assume that the entrepreneur commits to his regular selling price at the beginning of the first period under an advance selling setting. As the second reference model, reaching the regular selling period is not contingent on a successful sale in the first period. The entrepreneur can not assume that a successful campaign has happened when he commits to the regular selling price; therefore,

Figure C.2: Illustration of the third reference case in Appendix C.3



(a) $q_L < q_H \leq 2q_L$ (b) $q_H > 2q_L$

the expected profit functions of the entrepreneur with true product quality q_i when he is believed to be of q_j are given as follows. When $i = j = \{H, L\}$, $\Pi^i(P_1, P_2) = (1 - \frac{P_1}{q_i})P_1 + (1 - \frac{P_2}{q_i})P_2$. When $i \neq j$,

$$\Pi^{HL}(P_1, P_2) = (1 - \tfrac{P_1}{q_L})P_1 + (1 - \tfrac{P_2}{q_H})P_2.$$

and

$$\Pi^{LH}(P_1, P_2) = \begin{cases} (1 - \frac{P_1}{q_H})P_1 + (1 - \frac{P_2}{q_L})P_2 & 0 < P_2 \leq q_L, \\ (1 - \frac{P_1}{q_H})P_1 & q_L < P_2 \leq q_H. \end{cases}$$

The reason why $\Pi^{LH}(P_1, P_2)$ is a piece-wise function is the same as explained after (10), that the low-quality entrepreneur has incentive to set $P_2 > q_L$ under asymmetric information case if the gain from treated as a high-quality type overcomes the loss of payoff in the second period. The feasible region for the high-quality entrepreneur under a separating equilibrium satisfies the following conditions,

$$\Pi^{LH}(P_1, P_2) \leq \Pi^{L*} = \tfrac{q_L}{2}, \quad \Pi^{H}(P_1, P_2) \geq \Pi^{HL*} = \tfrac{q_L}{4} + \tfrac{q_H}{4}. \tag{C.1}$$

Let (P^H_{1r3}, P^H_{2r3}) denote the separating equilibrium prices for the high-quality entrepreneurs in the third reference model. We can characterize the separating equilibrium in the following two cases.

i) $\underline{q_L < q_H \leq 2q_L}$ In this case, there is no $P_2 > q_L$ on the iso-profit curve of $\Pi^{LH}(P_1, P_2) = \Pi^{L*}$, as shown in Figure C.2(a). The separating equilibrium pricing pair for the high-quality entrepreneur is

$$(P^H_{1r3}, P^H_{2r3}) = (\tfrac{q_H}{2}, \tfrac{q_L + \sqrt{q_L(q_H - q_L)}}{2}), \tag{C.2}$$

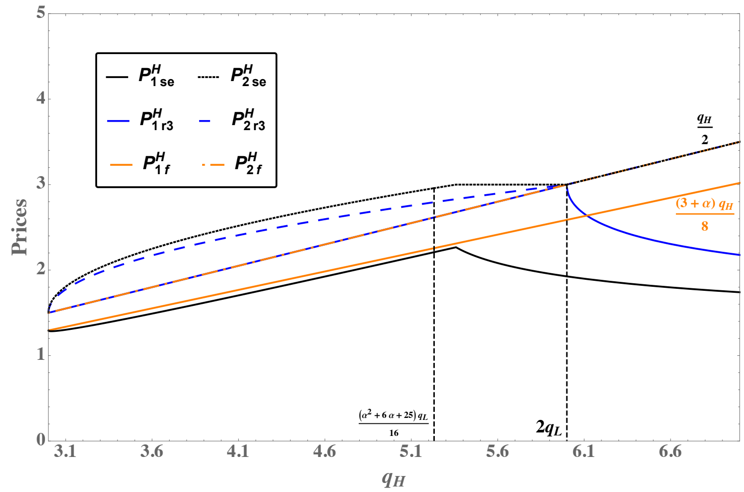
which indicates the high-quality entrepreneur only distorts his regular selling price, as the optimal prices for the third reference model under full information is $(\frac{q_H}{2}, \frac{q_H}{2})$.

ii) $\underline{q_H > 2q_L}$ In this case, there is $P_2 > q_L$ on the iso-profit curve of $\Pi^{LH}(P_1, P_2) = \Pi^{L*}$, as shown in Figure C.2(b). The separating equilibrium pricing pair for the high-quality entrepreneur is

$$(P^H_{1r3}, P^H_{2r3}) = (\tfrac{q_H - \sqrt{q_H(q_H - 2q_L)}}{2}, \tfrac{q_H}{2}). \tag{C.3}$$

which indicates the high-quality entrepreneur only distorts his funding price in equilibrium. We can establish the following proposition by comparing the characterized equilibrium prices in crowdfunding, advance selling and the optimal prices in the full-information cases.

Figure C.3: Comparison of the Separating Equilibrium (Optimal) Prices in the Three Cases



Notes. There are overlaps for $P^H_{1r3} = P^H_{2f} = \frac{q_H}{2}$ when $q_H \le 2q_L$, and $P^H_{2se} = P^H_{2f} = P^H_{2r3} = \frac{q_H}{2}$ when $q_H > 2q_L$.

Proposition C.1. *When the gap in potential quality levels is not large, i.e.,* $q_H \le \frac{(\alpha^2+6\alpha+25)q_L}{16}$*, we can establish the following result (without the constaint of* $P_1 \ge T$*):*

i) $P^H_{1se} < P^H_{1f} < P^H_{1r3}$.

ii) $P^H_{2se} > P^H_{2r3} > P^H_{2f}$.

Figure C.3 depicts our findings in the above proposition. In particular, when the gap in potential quality levels is not large, the high-quality entrepreneur downward distorts his equilibrium funding price in crowdfunding. At the same time, he increases his equilibrium regular selling price, as highlighted in the paper. Part (ii) of the above proposition also indicates that the distortion of the equilibrium regular selling price in crowdfunding is greater than that in the third reference case (the advance selling settings), as $P^H_{2se} - P^H_{2f} > P^H_{2r3} - \frac{q_H}{2}$.

For large gaps in potential quality levels (i.e., $q_H \ge 2q_L$), the characterized separating equilibrium in Proposition B.1 and in the third reference case, allow us to investigate how contingency of the regular selling period on a successful campaign determines the optimal pricing strategy of the high-quality entrepreneur in the separating equilibrium. As Figure C.3 demonstrates, for large gaps in potential quality levels, the entrepreneur does not distort his regular selling price as any further upward distortion in the committed price cannot prevent the low-type from mimicking. The only choice for the high-quality entrepreneur is to reduce his funding price. This is clear through a sharp drop in funding prices in Figure C.3 for large gaps in potential quality levels ($\acute{P}_1 < P^H_{1r3}$). In other words, for relatively large gaps in quality levels, while the high-quality entrepreneur might set the regular selling prices to push a mimicking low-type out of the regular selling period, he decreases his funding price further to increase the mimicking cost of a low-quality one.

Proof of Proposition C.1 It is easy to verify that $P^H_{1f} < P^H_{1r3}$, as $P^H_{1f} = \frac{3+\alpha}{8} q_H$ and $P^H_{1r3} = \frac{q_H}{2}$. Similarly, as $P^H_{2r3} > P^H_{2f}$, it is easy to have $P^H_{2r3} = \frac{q_H}{2}$ and $P^H_{2f} = \frac{q_L + \sqrt{q_L(q_H - q_L)}}{2}$ when $q_H \le . \frac{(\alpha^2+6\alpha+25)q_L}{16} < 2q_L$

As discussed above, the optimal pricing pair (P^H_{1f}, P^H_{2f}) locates inside the iso-profit curve $\mathcal{N}$, and it is also on the line of $4P_1 + (1-\alpha)P_2 = 2q_H$. It is also easy to see that P_1 decreases in P_2 for (P_1, P_2) on $4P_1 + (1-\alpha)P_2 = 2q_H$, as illustrated in Figure 4(b). Therefore, $P^H_{1se} < P^H_{1f}$ and $P^H_{2se} > P^H_{2r3}$, as (P^H_{1se}, P^H_{2se}) is the intersection of $4P_1 + (1-\alpha)P_2 = 2q_H$ and $\mathcal{N}$. $\square$

Appendix D: Intuitive criterion and elimination of pooling equilibrium

D.1. Refinement of pooling equilibrium in one-price signaling

In this subsection, we show the elimination of pooling equilibrium by intuitive criterion in one-price signaling. Suppose there is a pooling equilibrium, in which the entrepreneur sets p_{1P} for both quality levels $i \in \{H, L\}$. The entrepreneur's expected profit in the regular selling period is as follows,

$$\pi_{2P}^{i}(p_2|T \leq p_1 \leq q_P) = \begin{cases} \alpha p_2 + (1-\alpha)(1-\frac{p_2}{q_i})p_2 & 0 < p_2 < \frac{p_1 q_i}{q_P}, \\ \frac{\alpha}{1-p_1/q_P}(1-\frac{p_2}{q_i})p_2 + (1-\alpha)(1-\frac{p_2}{q_i})p_2 & \frac{p_1 q_i}{q_P} \leq p_2 \leq q_i, \end{cases}$$

where $q_P = aq_H + (1-a)q_L$ is the customers' expected product quality. The optimal regular selling price and the corresponding optimal profit in the regular selling period are given by,

$$\left(p_{2P}^{i*}, \pi_{2P}^{i*}\right) = \begin{cases} \left(\frac{q_i}{2}, (\frac{\alpha}{1-p_1/q_P} + (1-\alpha))\frac{q_i}{4}\right) & T \leq p_1 < \frac{q_P}{2}, \\ \left(\frac{p_1 q_i}{q_P}, \frac{\alpha p_1 q_i}{q_P} + (1-\alpha)(1-\frac{p_1}{q_P})\frac{p_1 q_i}{q_P}\right) & \frac{q_P}{2} \leq p_1 < \frac{q_P}{2(1-\alpha)} \wedge q_P, \\ \left(\frac{q_i}{2(1-\alpha)}, \frac{\alpha q_i}{2(1-\alpha)} + (1-\frac{1}{2(1-\alpha)})\frac{q_i}{2}\right) & \frac{q_P}{2(1-\alpha)} \wedge q_P \leq p_1 \leq q_P. \end{cases}$$

Given the optimal expected profit in the second period, the entrepreneur's pooling profit in the first period for each type $i \in \{H, L\}$ is,

$$\pi_P^i(p_{1P}) = Pr(\theta_c q_P - p_{1P} \geq 0)(p_{1P} + \pi_{2P}^{i*}) = (1 - \frac{p_{1P}}{q_P})(p_{1P} + \pi_{2P}^{i*}).$$

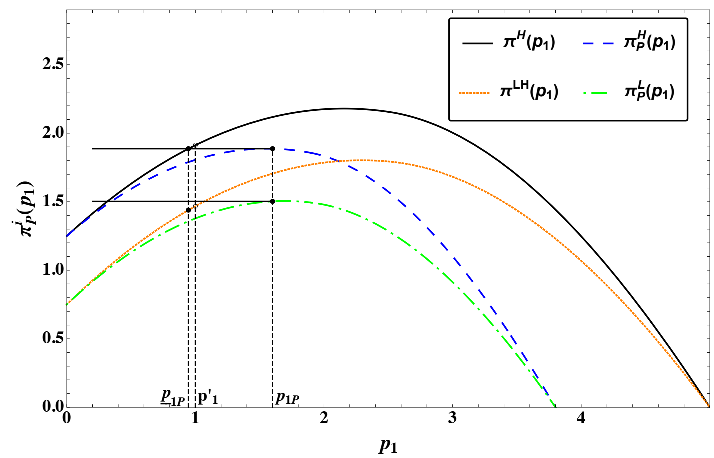
We look for a price $\mathring{p}_1$ different from p_{1P} such that the low-quality entrepreneur does not prefer to deviate from p_{1P} to $\mathring{p}_1$, even if such a deviation would induce customers to believe that the entrepreneur is of high quality; whereas, the high-quality entrepreneur does have the incentive to deviate if the deviation would induce the customers to believe that the product quality is high. Assume that customers believe the quality is high when observing a pricing level p_1 different from p_{1P}, then the entrepreneur's profit functions for the high and low quality entrepreneurs can be written as $\pi^H(p_1) = (1 - \frac{p_1}{q_H})(p_1 + \pi_2^{H*})$ and $\pi^{LH}(p_1) = (1 - \frac{p_1}{q_H})(p_1 + \pi_2^{L*})$, respectively, where π_2^{H*} and π_2^{L*} are characterized in Lemma 1.

Similar to the proof of Lemma 2, there is a unique $\overline{p}_{1P}$ that satisfies $\pi^{LH}(\overline{p}_{1P}) = \pi_P^L(p_{1P})$, and a unique $\underline{p}_{1P}$ that satisfies $\pi^H(\underline{p}_{1P}) = \pi_P^H(p_{1P})$, with $\overline{p}_{1P} > \underline{p}_{1P}$. It is straightforward to check that for any $p_1' \in [\underline{p}_{1P}, \overline{p}_{1P}]$, $\pi^{LH}(p_1) < \pi_P^L(p_{1P})$ and $\pi^H(p_1) > \pi_P^H(p_{1P})$. Hence, the entrepreneur with the low quality product has no incentive to deviate from the pooling equilibrium p_{1P} to $\mathring{p}_1$ while a high-quality one has the incentive to deviate from p_{1P} to $\mathring{p}_1$, assuming a deviation to $\mathring{p}_1$ persuades customers to believe that the product quality is high. In the pooling equilibrium, since customers assign a positive probability to the product to be of high quality, the expected profit of the low-quality entrepreneur cannot be lower than his optimal profit in full information as customers willingness to pay increases, i.e., $\pi_P^L(p_{1P}) \geq \pi^{L*}$, and we have $\overline{p}_{1P} > \overline{p}_1 > T$. The existence of such a $\mathring{p}_1$ indicates that any pooling equilibrium would be refined by the intuitive criterion (see Figure D.1(a) for a demonstration).

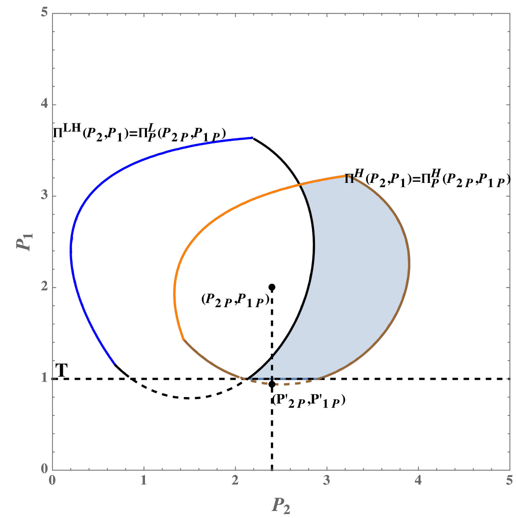
D.2. Refinement of pooling equilibrium in two-price signaling

We demonstrate that the established separating equilibrium is the unique equilibrium that survives the intuitive criterion. Suppose there is a pooling equilibrium in two-price signaling, in which the entrepreneur

Figure D.1: Demonstration of the Refinement of the Pooling Equilibrium by the Intuitive Criterion



(a) One-price signaling refinement



(b) Two-price signaling refinement

Notes. The parameters are $q_H = 4$, $q_L = 3$, $q_P = 3.2$, $b = 0.75$, $T = 0.2$ and $p_{1P} = 1.6$ for (a) and $H = 5$, $L = 3$, $q_P = 4$, $P_{1P} = 2$, $P_{2P} = 2.4$ and $T = 0.9$ for (b).

sets (P_{1P}, P_{2P}) for $i \in \{H, L\}$. Given the pooling equilibrium pricing pair, the entrepreneur's profit in the funding period without the financing constraint $P_1 \geq T$ for $i \in \{H, L\}$ is given by,

$$\Pi_P^L(P_{1P}, P_{2P}) = \begin{cases} (1 - \frac{P_{1P}}{q_P})\left(P_{1P} + \alpha P_{2P} + (1-\alpha)(1 - \frac{P_{2P}}{q_L})P_{2P}\right) & \frac{q_P P_{2P}}{q_L} \leq P_{1P} \leq q_P, P_{2P} < q_L, \\ (1 - \frac{P_{1P}}{q_P})\left(P_{1P} + \frac{\alpha}{1 - P_{1P}/q_P}(1 - \frac{P_{2P}}{q_L})P_{2P} + (1-\alpha)(1 - \frac{P_{2P}}{q_L})P_{2P}\right) & 0 \leq P_{1P} < \frac{q_P P_{2P}}{q_L} < q_P, \\ (1 - \frac{P_{1P}}{q_P})P_{1P} & P_{2P} \geq q_L, \end{cases}$$

and

$$\Pi_P^H(P_{1P}, P_{2P}) = \begin{cases} (1 - \frac{P_{1P}}{q_P})\left(P_{1P} + \alpha P_{2P} + (1-\alpha)(1 - \frac{P_{2P}}{q_H})P_{2P}\right) & \frac{q_P P_{2P}}{q_H} \leq P_{1P} \leq q_P, \\ (1 - \frac{P_{1P}}{q_P})\left(P_{1P} + \frac{\alpha}{1 - P_{1P}/q_P}(1 - \frac{P_{2P}}{q_H})P_{2P} + (1-\alpha)(1 - \frac{P_{2P}}{q_H})P_{2P}\right) & 0 \leq P_{1P} < \frac{q_P P_{2P}}{q_H}. \end{cases}$$

Similar to the refinement in one-price signaling, we look for a pricing pair $(\mathring{P}_1, \mathring{P}_2)$ different from (P_{1P}, P_{2P}), such that the low-quality entrepreneur has no incentive to deviate from (P_{1P}, P_{2P}) to $(\mathring{P}_1, \mathring{P}_2)$ even when he is believed to be of high quality and the high-quality entrepreneur has the incentive to deviate, if the deviation persuades customers to believe he is of high quality.

In the following, we assume a price pair $(\mathring{P}_1, \mathring{P}_2)$ with $P_{2P} < q_L$. The case with $P_{2P} > q_L$ is similar, therefore, is dropped. Assume that the customers believe the quality is high when observing a price pair (P_1, P_2) different from (P_{1P}, P_{2P}). Then the entrepreneur's profit function follows the profit function $\Pi^H(P_1, P_2)$ in (8) with a high-quality level and the profit equation $\Pi^{LH}(P_1, P_2)$ in (10) with a low-quality level.

Let $P'_{2P} = P_{2P}$, there exists a unique $0 < P'_{1P} < P_{1P}$ such that $\Pi^H(P'_{1P}, P'_{2P}) = \Pi_P^H(P_{1P}, P_{2P})$; moreover, $\Pi^H(P_1, P'_{2P})$ increases at P_1. We verify $\Pi^{LH}(P'_{1P}, P'_{2P}) < \Pi_P^L(P_{1P}, P_{2P})$ in the following.

$$\Pi^{LH}(P'_{1P}, P'_{2P}) = \Pi^H(P'_{1P}, P'_{2P}) + (\alpha + (1-\alpha)(1 - \frac{P'_{1P}}{q_H}))(\frac{P'_{2P}}{q_H} - \frac{P'_{2P}}{q_L})P'_{2P},$$

and

$$\Pi_P^L(P_{1P},P_{2P}) = \Pi_P^H(P_{1P},P_{2P}) + (\alpha + (1-\alpha)(1-\tfrac{P_{1P}}{q_P}))(\tfrac{P_{2P}}{q_H} - \tfrac{P_{2P}}{q_L})P_{2P}.$$

Since $P_{1P} > P'_{1P}$, $P_{2P} = P'_{2P}$ and $q_H > q_P > q_L$, we get $(\alpha + (1-\alpha)(1-\frac{P'_{1P}}{q_H}))(\frac{P'_{2P}}{q_H} - \frac{P'_{2P}}{q_L})P'_{2P} < (\alpha + (1-\alpha)(1-\frac{P_{1P}}{q_P}))(\frac{P_{2P}}{q_H} - \frac{P_{2P}}{q_L})P_{2P} < 0$. Meanwhile $\Pi^H(P'_{1P},P'_{2P}) = \Pi_P^H(P_{1P},P_{2P})$, so we have $\Pi^{LH}(P'_{1P},P'_{2P}) < \Pi_P^L(P_{1P},P_{2P})$. Therefore, $(\mathring{P}_1,\mathring{P}_2) = (P'_{1P}+\epsilon, P'_{2P})$ is the pricing pair we need.

In fact, any pricing pair $(\mathring{P}_1,\mathring{P}_2)$ that belongs to the region between the two iso-profit curves satisfies

$$\Pi^H(\mathring{P}_1,\mathring{P}_2) > \Pi_P^H(P_{1P},P_{2P}),$$
$$\Pi^{LH}(\mathring{P}_1,\mathring{P}_2) < \Pi_P^L(P_{1P},P_{2P}).$$

Hence, the entrepreneur with the low-quality product has no incentive to deviate from the pooling equilibrium (P_{1P},P_{2P}) to $(\mathring{P}_1,\mathring{P}_2)$ while the high-quality one has the incentive to deviate from (P_{1P},P_{2P}) to $(\mathring{P}_1,\mathring{P}_2)$, assuming a deviation to $(\mathring{P}_1,\mathring{P}_2)$ leads the customers to believe that the product quality is of high quality. The existence of such a pricing pair $(\mathring{P}_1,\mathring{P}_2)$ indicates that the intuitive criterion would refine any pooling equilibrium (see Figure D.1(b) for demonstration).

Appendix E: Discussion and Extensions

To improve our exposition in the paper, we have introduced several simplifying assumptions. In this section, we present two extensions to our model and discuss the robustness of our findings. First, we comment on the effect of customer heterogeneity and market updating on our findings, and later we discuss the role of the relative market sizes in the funding and regular selling periods.

E.1. Customer heterogeneity and exogenous market updating

The introduction of customer heterogeneity and exogenous market updating increases the complexity of the signaling model. In what follows, we make a simplifying assumption on the correlation between customers' tastes in the funding and regular selling periods, which guarantees analytical tractability, but first, we comment on their effects in general settings. It is reasonable to assume that customers have different tastes for a product on display in crowdfunding settings. In particular, part of the customers may be fans or family members of the entrepreneur; therefore, they are enthusiastic to back the project. Also, some regular customers check crowdfunding platforms to find and back exciting projects. It seems innocuous to assume that willingness to pay is less than fans among regular customers. The presence of high-valuation customers increases both the chance of success and the amount of the raised fund in the funding period. Still, success in the funding period is probabilistic; its chance decreases in the entrepreneur's funding price. Another potential extension of the model is to incorporate the fact that the entrepreneur has access to the feed-backs of his backers in the funding period when he prices in the regular selling period. Most online crowdfunding platforms allow backers to leave comments on products they backed after receiving their product. In the model that we present, we introduce two assumptions. First, we assume that learning mainly happens as backers experience the product and reveal their valuation to the public through their comments and reviews on crowdfunding platforms, social media, or free product review websites like G2 Crowd and Angie's List (or even through correspondence with the entrepreneur). This serves as a signal on potential customers' valuation in the second period. The next assumption is that customers' valuations in the funding and regular selling periods are independent for analytical tractability purposes. In what follows, we introduce a model with heterogeneous customers in the funding period and an exogenous market signal that is amenable to analysis.

Assume that customers in the funding period are heterogeneous. To keep it simple, assume that customers are mainly comprised of high valuation customers (i.e., fans, who come from the entrepreneurs' social circle or they are avid fans of the product) and regular customers (Kuppuswamy and Bayus 2017, Paolo et al. 2018). The high valuation customers have the maximum taste for the product, which we normalize to one, i.e., $\theta_1 = 1$, or equivalently, $U = q - p_1$. Regular customers are also interested in the project, but their enthusiasm for the project is less than the avid fans. Their taste parameter is assumed to be unknown but uniformly distributed between 0 and 1, i.e., $\tilde{\theta}_1 \sim U[0,1]$. We normalize the market sizes of the high and regular valuation customers to β and $1-\beta$ $(0 < \beta < 1)$, respectively, to normalize the market size in the funding period to one. Since we have normalized the potential market size in the funding period to one, the campaign would fail for sure if $p_1 < T$. As the customers' taste parameter satisfies $0 \leq \theta \leq 1$, the crowdfunding price satisfies $p_1 \leq q$; otherwise, no one will buy the product. We can characterize the campaign's success as follows. When $T > \beta q$, the maximum contribution from fans (i.e., βq) is insufficient for the campaign's success; thus, the entrepreneur needs support from both types of customers, and the campaign's success probability is $(1 - \frac{p_1}{q})$ with $T \leq p_1 \leq q$. When $T \leq \beta q$, we have the following two cases: when $p_1 \in [T, T/\beta)$, the campaign will succeed if both types of the customers support it, thus campaign success probability is still given by $(1 - \frac{p_1}{q})$; when $p_1 \in [T/\beta, q]$, the campaign will succeed for sure as the high valuation customers' contribution to the campaign, βp_1 exceeds T.

The entrepreneur conducts market research at the beginning of the regular selling period, which generates a signal $s \in \{G, B\}$. When customers in the regular market have a relatively high or low valuation of the product, the probability that the entrepreneurs' market research reveals the true relative valuation of customers to the entrepreneur is b. In particular, the probability of G signal when $\theta_2 = \theta^H$ or B signal when $\theta_2 = \theta^L$ is b; therefore, $Pr(s = G|\theta_2 = \theta^H) = b$, $Pr(s = B|\theta_2 = \theta^H) = 1 - b$, $Pr(s = G|\theta_2 = \theta^L) = 1 - b$ and $Pr(s = B|\theta_2 = \theta^L) = b$, with $1/2 \leq b \leq 1$. The proposed structure for the market signal is similar to the confusion matrix in the multi-class classification problem, where b and $1 - b$ are essentially sensitivity and specificity for a binary classification problem. While the prior belief about customers' taste in the regular selling period assigns the same probability to the high or low interest scenarios, the market signal G reveals to the entrepreneur that the probability $\theta_2 = \theta^H$ is

$$Pr(\theta_2 = \theta^H|s = G) = \frac{Pr(s = G|\theta_2 = \theta^H)Pr(\theta_2 = \theta^H)}{Pr(s = G)} = \frac{\frac{1}{2}b}{\frac{1}{2}b + \frac{1}{2}(1-b)} = b, \tag{E.1}$$

and $Pr(\theta_2 = \theta^L|s = G) = 1 - b$. Similarly, $Pr(\theta_2 = \theta^H|s = L) = 1 - b$ and $Pr(\theta_2 = \theta^L|s = L) = b$.

Since we assume that $\alpha = 0$, the campaign's success does not reveal any information about the regular selling period customers' taste to the entrepreneur, but he can receive exogenous market signals on customers' tastes. Interestingly, we found that all of the major findings in the paper still hold. A detailed model and analysis are available from the authors. In particular, we can show that a low enough funding price can still signal high quality, while two-price signaling reduces the entrepreneur's signaling costs. Learning through a market signal reduces the advantage of price commitment (which might result in the dominance of one-price signaling), and two-price signaling is usually preferred to one-price signaling. It exists for a wider range of financing target levels. The drivers for quality signaling do not change as we introduce either heterogeneous customers or market updating into our model.

The market signals on customers' tastes in the regular selling period are advantageous for the one-price signaling mechanism. We show that one-price signaling can dominate price commitment for small enough gaps in high and low-quality levels. It allows flexible pricing in the regular selling period as the entrepreneur receives market signals on customers' tastes. It is not surprising that for moderate and large gaps in quality levels, the distortion in the funding price in one-price signaling dominates the potential benefit of flexible pricing; therefore, two-price signaling dominates one-price signaling.

E.2. Regular selling period market size

The base model assumes the same market sizes in both the funding and the regular selling periods. This allows us to disentangle the drivers of the separating equilibrium from the relative market sizes effect. This section comments on the potential effects of the relative market sizes in the first and second periods.

In the one-price signaling, as the market size in the regular selling period increases, the advantage of the high-quality entrepreneur over the low-quality one in the regular selling period increases. Such an advantage makes reaching the second period even more enticing to the high-quality entrepreneur. Still, the high-quality entrepreneur can find a low-enough funding price that can separate him from the low-quality one. Similarly, it is clear that as the market size in the regular selling period decreases, a small advantage over the low-quality entrepreneur makes the high-quality entrepreneur reduce his funding price to very low prices. A separating equilibrium would exist for low financing needs; otherwise, just a pooling equilibrium would arise.

In the two-price signaling, a high enough market size may result in costless signaling. In the optimal pricing pair under full information for the high-quality entrepreneur, the optimal regular selling price might be so large that the low-quality entrepreneur finds it quite costly to mimic. Therefore, even the first best solution might arise as the separating equilibrium. In advance selling literature, Chen and Jiang (2021) study the effect of the number of periods instead of the regular selling period market size as in our model. They show that the firm can signal his quality by committing to high future prices, especially as the number of periods increases, because such commitments would impose higher opportunity costs on low-quality firms. Similar to our conjecture, with a long enough horizon, costless signaling would arise.

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