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Crowdfunding, demand uncertainty, and moral hazard - a mechanism design approach

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Abstract

Crowdfunding challenges the traditional separation between finance and marketing. It creates economic value by reducing demand uncertainty, which enables a better screening of positive NPV projects. Entrepreneurial moral hazard threatens this effect. Using mechanism design, mechanisms are characterized that induce efficient screening, while preventing moral hazard. "All-or-nothing" reward-crowdfunding platforms reflect salient features of these mechanisms. Efficiency is sustainable only if expected gross returns exceed twice expected investment costs. Constrained efficient mechanisms exhibit underinvestment. With limited consumer reach, crowdfunders become actual investors. Crowdfunding complements rather than substitutes traditional entrepreneurial financing, because each financing mode displays a different strength.

JEL classification codes: D82, G32, L11, M31

Keywords: Crowdfunding, finance, marketing, demand uncertainty, moral hazard

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1 Introduction

Crowdfunding has, in recent years, attracted much attention as an alternative mode of entrepreneurial financing: through the internet many individuals — the crowd — provide funds to the entrepreneur.[1] In the context of "reward-crowdfunding", this crowd consists of the very consumers which the entrepreneur intends to target with her final product. As a result, reward-crowdfunding leads to a transformation of entrepreneurship, severing the traditional separation of finance and marketing.[2]

Figure 1 illustrates this transformation. In the traditional model, venture capitalist (or banks) attract capital from consumers to finance entrepreneurs, who subsequently use this capital to produce goods and market them to consumers. In this traditional model, finance and marketing are naturally separated and run along different channels. Under reward-crowdfunding, finance and marking run along the same channel: the crowdfunding platform.

The recent popularity of crowdfunding raises important questions about the economic viability of this new entrepreneurial model and, in particular, about replacing the financial intermediary.[3] Economic theory provides clear efficiency arguments in favor of a specialized financial intermediary. For instance, the seminal paper Diamond (1984) points out that by coordinating investment through a single financial intermediary, free-riding problems associated with monitoring the borrower's behavior are circumvented. Indeed, monitoring to limit a borrower's moral hazard seems especially important for entrepreneurial financing. Entrepreneurs are typically new players in the market, who, in contrast to well-established firms, have not yet had the ability to build up a reputation to demonstrate their trustworthiness.

[1] Time (2010) lists crowdfunding as one of the "Best Inventions of 2010", while Economist (2012) reports that the "talk of crowdfunding as a short-lived fad has largely ceased". On the policy side, the JOBS Act from 2012 and SEC (2015) set the foundations to raise capital through securities offerings using the internet in the US.

[2] In contrast, "equity-crowdfunding" upholds the traditional separation between finance and marketing, because the consumers and the crowd-investors are typically not the same economic agents.

[3] Mollick (2014) defines crowdfunding as "efforts by entrepreneurial individuals and groups – cultural, social, and for-profit – to fund their ventures by drawing on relatively small contributions from a relatively large number of individuals using the internet, *without standard financial intermediaries*" (emphasis added).

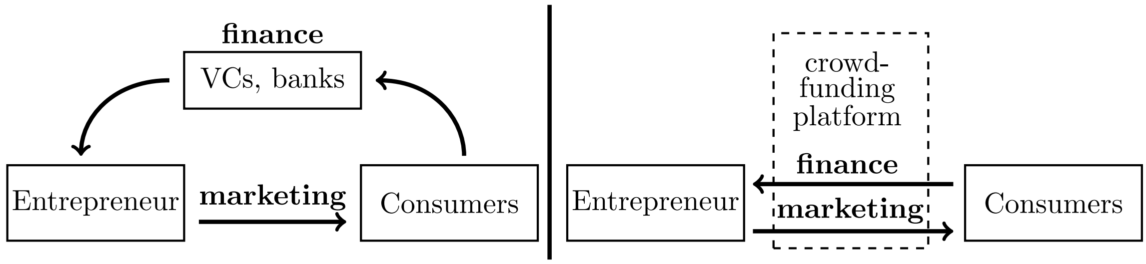

Figure 1: Traditional entrepreneurial financing (left) vs. reward-crowdfunding (right)

Hence, if crowdfunding is a viable alternative to traditional finance, it must provide relative efficiency gains from a different origin. This paper argues that it does indeed do so. Reward-crowdfunding provides a surprisingly effective way of addressing the second main obstacle to entrepreneurial financing: reducing demand uncertainty to allow a better screening of positive NPV projects.[4]

Indeed, outside investors deciding on a new entrepreneurial project face two basic problems: 1) How to be sure that the entrepreneur will and can realize the intended project and 2) how to be sure that the intended project generates enough consumer demand so that it has a positive NPV.

The premise of this paper is that, while in the spirit of Diamond (1984) the traditional model has clear efficiency advantages in dealing with problem 1, i.e. dealing with entrepreneurial moral hazard, the reward-crowdfunding model has clear advantages in dealing with problem 2, i.e. dealing with demand uncertainty.[5] Before illustrating this efficiency effect of crowdfunding by a simple example, we first discuss how reward-crowdfunding in practise actually works.

Collecting funds of more than 1.5 billion dollars since its conception in 2009, the most successful crowd-funding platform to date is Kickstarter. It implements crowdfunding as follows. First, the entrepreneur describes her project, consisting of the following three elements: 1) a description of the reward to the consumer, which is typically the entrepreneur's final product; 2) a pledge level, p, for each consumer; and

[4]Agrawal et al. (2014) mention this potential advantage of crowdfunding, but provide no formal analysis. They also stress the problems of moral hazard in crowdfunding.

[5]Interestingly, one of the most successful crowdfunding campaigns on Kickstarter, Pebble, first applied for VC funding, but only received it after proving consumer demand through its crowdfunding campaign: "What venture capital always wants is to get validation, and with Kickstarter, he could prove there was a market" (Dingman 2013).

3) a target level, T, which triggers the execution of the project. Second, consumers pledge contributions, say $\tilde{n}$, and if the aggregate pledged contributions, $\tilde{n}p$, exceed the target level, T, the entrepreneur obtains the pledged contributions and must in return deliver to each pledged consumer his or her promised rewards. If the pledged contributions lie below the target level, the project is cancelled; consumers withdraw their pledges and the entrepreneur has no obligations towards the consumers. Hence, given a specified reward, the pair (p, T) defines the crowdfunding scheme consisting of a pledge level p and a target level T.

As a simple illustration of a crowdfunding scheme (p, T) that resolves demand uncertainty, consider a "crowd" represented by only a single representative consumer.[6] Suppose that the good's value to this consumer is either high, $v_h = 1$, or low, $v_l = 0$, each with probability 1/2. Let $I = 3/4$ represent the development costs which need to be invested before the good can be produced. Abstracting from any other production costs, the project has a positive NPV in the high valuation state v_h, but not in the low or the expected state of 1/2.

Hence, even if the entrepreneur had the required cash, she would not invest if she cannot elicit the consumer's valuation before hand; the project's expected valuation of 1/2 falls short of the investment cost of 3/4. Clearly, a venture capitalist facing the entrepreneur's business plan has a similar problem, even if, due to his experience with similar projects, he may be a somewhat better judge of the consumer's valuation than the entrepreneur. The main point to see is however that the crowd-funding scheme $(p, T) = (1, 1)$ resolves all demand uncertainty and screens out the positive NPV project naturally. It even allows the entrepreneur to extract the project's entire surplus. Indeed, facing the scheme $(p, T) = (1, 1)$, the consumer pledges only when $v = 1$ and the investment is triggered only in the high valuation state $v = 1$.

The extreme example not only illustrates the main efficiency effect of crowdfunding, but also identifies three crucial ingredients which yield the economic benefit of crowdfunding: 1) the presence of fixed development costs; 2) uncertainty about whether the demand of consumers is large enough to recover the development costs; and 3) a trigger level that enables conditional investment. The first two ingredients

[6] A single agent illustrates well the main, first-order effect of crowdfunding. Yet, it hides other effective properties of the scheme: mitigating strategic uncertainty and coordination problems.

are the defining features of entrepreneurial financing. The third ingredient is the defining feature of a so-called "all-or-nothing" crowdfunding platform.[7]

Yet, counteracting this positive effect of crowdfunding is the problem of entrepreneurial moral hazard. How can a crowd ensure that the entrepreneur's produces a final product that lives up to its initial promises, how can it ensure that the entrepreneur does not squander the money, or how to prevent the entrepreneur from simply making a run with the money after obtaining it?

An analysis of crowd-funding without explicit consideration of moral hazard problems seems therefore incomplete. As it turns out, this is the more so, because the benefits of reducing demand uncertainty interacts directly with the moral hazard problem: a reduction in demand uncertainty intensifies moral hazard.

In a nutshell, our formal analysis of optimal crowdfunding mechanisms yields the following results: 1) Optimal mechanisms condition the entrepreneur's investment decision on the sum of reported consumer valuations. 2) Optimal mechanisms do not require entrepreneurs to refund consumers so that consumers do not act as investors. 3) To reduce the threat of moral hazard, optimal mechanisms defer payments to the entrepreneur. 4) Because the moral hazard problem interacts with the reduction in demand uncertainty, optimal mechanisms resolve demand uncertainty only partially. 5) Because the moral hazard problem stands in conflict with the entrepreneur's need for capital, first-best efficient outcomes are unattainable if the ex ante expected returns of the project are close to the entrepreneur's ex ante expected capital costs. 6) Constrained efficient mechanisms display underinvestment but not overinvestment.

Whereas result 5 and 6 are of a clear normative nature, the first four results are positive. The "all-or-nothing" crowdfunding platforms reflect the 1st feature, while all current reward-crowdfunding platforms reflect the 2nd feature. Apart from the platform PledgeMusic, current platforms do not reflect the 3rd feature and currently all crowdfunding platforms announce publicly the total amount of pledges, implying they also do not reflect the 4th feature. These two latter observations confirm anecdo-

[7] Crowdfunding platforms using an "all-or-nothing" pledge schemes are, for instance, Kickstarter, Sellaband, and PledgeMusic. The "keep-what-you-raise" model, where pledges are triggered even if the target level is not reached is an alternative scheme that is popular for platforms more orientated towards social projects such as GoFundMe.

tal evidence that moral hazard is currently not a major issue, despite popular warnings of the opposite. An extension of our model that captures the limited consumer reach of current crowdfunding platforms, offers an explanation. Due to their limited reach, a successful entrepreneur expects to sell her goods also to non-crowdfunding consumers. This prospect acts as a direct substitute for deferred payments. Yet, as crowdfunding becomes more popular and reaches more consumers, this effect will decline. An increase in the popularity of crowdfunding therefore intensifies problems of moral hazard. In line with out analysis, this may induce more platforms to follow the example of PledgeMusic to introduce deferred payouts or, as also suggested by our analysis, even limit the platform's transparency in order to limit the threat of moral hazard further.

The rest of the paper is organized as follows. The next section discusses the related literature. Section 3 introduces the setup and identifies the main trade-offs. Section 4 sets up the problem as one of mechanism design. Section 5 characterizes constrained efficient mechanisms. Section 6 relates optimal mechanisms to real-life crowdfunding mechanisms and examines extensions. Section 7 concludes. All formal proofs are collected in the appendix.

2 Related literature

Being a new phenomenon, the literature on crowdfunding is still relatively small and primarily of an empirical and case-based nature. Concerning crowdfunding's economic underpinnings, Agrawal et al. (2014) provide a broad introduction that highlights the main issues. They emphasize entrepreneurial moral hazard with explicit quotes from the popular press. They also explicitly mention that crowdfunding can reduce demand uncertainty, but do not study this aspect formally nor discuss the features of crowdfunding schemes that are especially helpful in this respect.

Belleflamme et al. (2014) is one of the few theoretical studies that deals specifically with crowdfunding. It addresses the question whether a crowdfunding entrepreneur is better off raising her capital by reward-crowdfunding or by equity-crowdfunding. Since the authors abstract from aggregate demand uncertainty, they do not identify the economic benefits of reward-crowdfunding in screening out projects. Instead, the benefits of crowdfunding stems from their assumption that consumers obtain an extra utility from participating in the crowdfunding scheme. In particular, they study the extent to which the different crowdfunding schemes enable the monopolistic entrepreneur to extract this additional utility.

The economic literature on demand uncertainty has mostly focused on its effect on equilibrium prices rather than on its effect on investment decisions (e.g., Klemperer and Meyer 1989, Deneckere and Peck 1995, Dana 1999). An exception is Jovanovic and Rob (1987), who study the dynamics of innovation, when firms can acquire information about the consumers' evolving tastes and introduce product innovations that cater to them. Even though these random evolving changes express demand uncertainty, the paper is only tentatively related to the current study, because the authors do not allow direct revelation mechanisms of the consumer's preferences.

The marketing literature explicitly addresses a firm's ability to reduce demand uncertainty through market research such as consumer surveys (e.g., Lauga and Ofek 2009). Ding (2007) however emphasizes that consumers need to be given explicit incentives for revealing information that reduces demand uncertainty. He especially takes issue with the reliance of marketing research on voluntary, non-incentivized consumer surveys. Interestingly, current crowdfunding schemes provide such explicit incentives naturally.

Ordanini et al. (2011) present a marketing based, qualitative case study on crowdfunding. They explicitly note that crowdfunding blurs the boundaries between marketing and finance and view the consumers' investment support as the foundational trait of crowdfunding that sets it apart from other marketing theories. They mainly study two equity- and a pure donation-crowdfunding scheme, but also report the case of Cameesa, a Chicago based clothing company which in 2008 introduced an "all-or-nothing" crowdfunding model similar to Kickstarter.

Empirical studies of crowdfunding try to identify the crucial features of crowdfunding projects. Studies such as Agrawal et al. (2011) and Mollick (2014) focus on the geographic origin of consumers relative to the entrepreneur. Kuppuswamy and Bayus (2013) show that social information (i.e., other crowdfunders' funding decisions) plays a key role in the success of a project. Focusing on equity-crowdfunding, Hildebrand, et al. (2013) identifies an increased problem of moral hazard.

3 Crowdfunding and the Information Trade-off

This section introduces the basic setup by expanding on the introductory example.

The entrepreneur

We consider a penniless entrepreneur, who needs an upfront investment of $I > 0$ from investors to develop her product. We assume that after developing it, the entrepreneur can produce the good at some marginal cost $c \in [0, 1)$. We also assume that the entrepreneur is crucial for realizing the project and cannot simply sell her idea to outsiders. This assumption marks our setup as an entrepreneurial one.

The crowd

The example of the introduction considered a representative consumer rather than a genuine, i.e. uncoordinated crowd. In order to show that crowdfunding schemes also deal effectively both with strategic uncertainty and potential coordination problems within the crowd, we consider an uncoordinated crowd of n independent consumers and denote a specific consumer by the index $i = 1, \ldots, n$.

A consumer i either values the good, $v_i = 1$, or not, $v_i = 0$.[8] The consumers' valuations are iid distributed with $Pr\{v = 1\} = \nu$ and $\Pr\{v = 0\} = 1 - \nu$.[9] This means that the number of consumers with value $v = 1$, which we express by n_1, is binomially distributed, $n_1 \sim B(n, \nu)$. It holds

$$\Pr\{n_1\} = \binom{n}{n_1} \nu^{n_1} (1 - \nu)^{n - n_1}.$$

Since the marginal costs c are smaller than 1, we can take n_1 as the potential demand of the entrepreneur's good and its randomness expresses the demand uncertainty.

Investing without demand uncertainty

Consider as a benchmark the case of perfect information, where the entrepreneur observes n_1 before deciding to invest. In this case, the entrepreneur can effectively

[8] The binary structure ensures that demand uncertainty expresses itself only concerning the question whether the entrepreneur should invest or not and does not affect actual pricing decisions. Subsection 6.3 discuss the implications of more general frameworks.

[9] The next section allows these probabilities to be consumer specific, but, in line with standard mechanism design, upholds the iid assumption.

condition her investment decision on the observed potential demand n_1. It is socially optimal that the entrepreneur invests if it is large enough to cover the costs of production $I + n_1 c$, ie if

$$n_1 \geq \bar{n} \equiv \frac{I}{1-c}.$$

In this case, the project generates an ex ante expected aggregate surplus of

$$S^* = \sum_{n_1=\bar{n}}^{n} \Pr\{n_1\}[(1-c)n_1 - I].$$

Note that by investing exactly when $n_1 \geq \bar{n}$ and, subsequently, charging a price $p = 1$ for the good, the entrepreneur can appropriate the full surplus and this behavior therefore represents an optimal strategy. Hence without demand uncertainty, the entrepreneur's incentives coincide with maximizing aggregate surplus and leads to an efficient outcome.

Investing with demand uncertainty

Next consider the setup with demand uncertainty, i.e., the entrepreneur must decide to invest I without knowing n_1, if she subsequently wants to sell the good at some price p. For given n_1 and some price $p > c$, the entrepreneur's profit is

$$\Pi(p|n_1) = \begin{cases} (p-c)n_1 - I & \text{if } p \in [0,1]; \\ 0 & \text{if } p > 1. \end{cases}$$

Clearly, for any n_1 the price $p = 1$ maximizes profits. It follows that expected maximum profits from investing is

$$\Pi = \left(\sum_{n_1=0}^{n} \Pr\{n_1\}(1-c)n_1 \right) - I.$$

It is therefore profitable to invest only if $\Pi \geq 0$. As the price $p = 1$ does not leave any consumer rents, the entrepreneur's profits coincides with aggregate welfare, but in comparison to the case of perfect demand information either of two economic distortions arise. For parameter constellations such that $\Pi < 0$, the entrepreneur will not produce the good and, hence, the inefficiency arises that the good is not produced for any $n_1 > \bar{n}$. For the parameter constellation $\Pi \geq 0$, the entrepreneur does invest I, but the inefficiency arises that she produces the good also for any $n_1 < \bar{n}$.

Crowd-funding

We next consider the case of demand uncertainty but by crowd-funding the investment through consumers. This means that the entrepreneur commits to a pair (p, T), where p is the pledge level of an individual consumer and T is a target (or trigger) level. As explained in the introduction, the interpretation is that if $\tilde{n}$ consumers make a pledge and the total amount of pledged funds, $\tilde{n}p$, exceeds T, then the entrepreneur obtains the total amount of pledged funds, invests and produces a good for each consumer who pledged. If the total amount of pledges does not exceed T, then the pledges are not triggered and the entrepreneur does not invest. Hence, investment takes place when at least T/p consumers make a pledge.

It is again easy to see that crowd funding enables the entrepreneur to extract the maximum aggregate surplus of S^*. For any $p \in (0, 1]$, it is optimal for the consumer to pledge p if and only if $v = 1$. As a result, exactly n_1 consumers sign up so that the sum of pledges equals $P = n_1 p$. Hence, the project is triggered whenever $T \leq n_1 p$. We conclude that the crowd-funding scheme (p, T) with $p \in (0, 1]$ yields the entrepreneur an expected profit

$$\Pi^c(p, T) = \sum_{n_1 = T/p}^{n} \Pr\{n_1\}[(1-c)p - I].$$

A price $p = 1$ and a trigger level $P = \bar{n}$ maximizes this expression, yielding an efficient outcome and enabling the entrepreneur to extract the associated expected surplus of S^*.

In comparison to the single agent examples of the introduction, it is worthwhile to point out two additional features of the crowdfunding scheme. First, the crowdfunding scheme circumvents any potential coordination problems between consumers. This is because of the schemes second feature that for an individual agent strategic uncertainty concerning the behavior and the private information of other agents do not matter. Because of the scheme's conditional pledge system which triggers the consumer's pledges only if enough funds are available, it is a (weakly) dominant strategy for each individual consumer i to pledge if and only if $v_i = 1$.

Moral hazard

The setup until now abstracted from any problems of moral hazard. Consumers are sure to obtain the good as promised if their pledge is triggered. In practise, consumers may however worry about the problem of moral hazard and whether the entrepreneur will in the end deliver a good that meets the initial specifications, or whether they will receive some good at all. We can see all these different forms of moral hazard as a weaker version of the problem that the entrepreneur simply takes total pledges and does not invest at all. Clearly, if she could, she would do so, because she is indeed better of running off with these pledges instead of incurring the additional costs $I + cP/p$ for realizing the project. In the face of such moral hazard problems, rational consumers will not crowdfund the project and the crowdfunding scheme collapses.

The root of this collapse is clear: the entrepreneur receives the pledged funds *before* she actually invests and nothing after realizing the projects. Hence, one way to mitigate this problem is to change the crowdfunding scheme such that the entrepreneur obtains the consumer's pledges only *after* having produced the good. Such a delay in payments is however possible only up to some degree because the penniless entrepreneur needs at least the amount I to develop the product.

As a first step to address the moral hazard problem, we simply adjust our interpretation of a crowdfunding scheme (p, T) as follows. As before, the price p represents the pledge-level of an individual consumer and T the target level which the sum of pledges, P, has to meet before the investment is triggered. Different from before however, the entrepreneur first obtains only the required amount I in order to develop the product and she obtains the remaining part $P - I$ only after delivering the good to consumers.[10]

In order to see whether this alternative implementation of the crowdfunding scheme prevents the entrepreneur from running off with the collected money, note that the entrepreneur obtains the payoff I from a run and the payoff $P - I - cP/p$ from realizing the project. Hence, she has no incentive to run if

$$P \geq \frac{2I}{(1-c)p}. \tag{1}$$

We conclude that a crowdfunding scheme $(p, T) = (1, 2I/(1-c))$ with delayed payments solves the moral hazard problem. For such a scheme, a consumer with value

[10]As explicitly stated on their website, PledgeMusic, a reward-crowdfunding site specialized in raising funds for recordings, music videos, and concerts, uses a scheme with deferred payouts to prevent fraud.

$v = 1$ is willing to pledge $p = 1$ and the scheme leads to an equilibrium outcome in which all consumers with $v = 1$ pledge and the project is triggered when at least T consumers have the willingness to pay of 1, ie if $n_1 > 2I/(1 - c)$. Although the scheme does prevent the moral hazard problem, note however that it does not attain the efficient outcome, because its trigger level is twice as large as the socially efficient one.

The information trade-off

Given the problem of moral hazard, a crowdfunding scheme with delayed final payments circumvents the moral hazard problem to some extent. Since this delayed scheme does does not yield an efficient outcome, the question arises whether even more sophisticated crowdfunding models exist that do better. To already give an indication of this, note that even though we praised the role of crowdfunding as a device to reduce demand uncertainty, the considered crowdfunding scheme actually reduces it too much when there is also a moral hazard problem. Indeed, with respect to choosing the efficient investment decision, the entrepreneur only needs to know whether n_1 is above or below $\bar{n}$. The exact value of n_1 is immaterial.

Yet, as inequality (1) reveals, the moral hazard problem intensifies if the entrepreneur obtains full information about P. As discussed, this inequality has to hold for any possible realization of $P \geq T$ in order to prevent the entrepreneur to take the money and run. Because the constraint is most strict for the case $P = T$, a crowdfunding scheme (p, T) does not lead to take the money and run if and only if

$$T \geq \frac{2I}{(1 - c)p}. \qquad (2)$$

In contrast, if the entrepreneur would only learn that P exceeds T, but not the exact P itself, then she rationally anticipates an *expected* payoff

$$E[P|P > T] - I - cE[P|P > T]/p$$

from not running with the money. Since the conditional expectation $E[P|P > T]$ exceeds T, a crowdfunding scheme that reveals only whether P exceeds T can deal with the moral hazard problem more efficiently.

Hence, in the presence of both demand uncertainty and the threat of moral hazard the information extraction problem becomes a sophisticated one. One neither wants too much nor too little information revelation. In order to find out the optimal amount of information revelation, we need to resort to the tools of mechanism design. For this reason the next section sets up and studies the crowdfunding problem as one of mechanism design.

4 Crowdfunding and Mechanism Design

In order to study the problem from the perspective of optimal mechanism design, we first have to make precise the available economic allocations. Consequently, we first describe the feasible economic allocation and, subsequently, discuss the mechanisms that can induce the feasible allocations.

Economic Allocations

Crowd-funding seeks to implement an allocation between one cash-constrained entrepreneur, player 0, and n consumers, players 1 to n. It involves monetary transfers and production decisions. Concerning monetary transfers, consumers can make a transfer to the entrepreneur in two periods in time. In period $t = 1$, before the entrepreneur has the possibility to invest and to develop the product, and in period $t = 2$, after the entrepreneur has had the possibility to invest. Let t_{i1} denote transfers of consumer i in period 1 and t_{i2} transfers of consumer i in period 2. Concerning the production decisions, the allocation describes whether the entrepreneur invests, $x_0 = 1$, or not, $x_0 = 0$, and whether the entrepreneur produces a good for consumer i, $x_i = 1$, or not, $x_i = 0$. Consequently, *an economic allocation a* is a combination (t, x) of transfers $t = (t_{11}, \ldots, t_{n1}, t_{12}, \ldots, t_{n2}) \in \mathbb{R}^{2n}$ and outputs $x = (x_0, \ldots, x_n) \in X \equiv \{0, 1\}^{n+1}$.

Feasible Allocations

By the very nature of the crowdfunding problem, the firm does not have the resources to finance the required investment $I > 0$. It is therefore financially constrained. As a consequence, the economic allocations in a crowdfunding problem exhibit the following inherent restrictions. First, the firm cannot make any net positive transfers to the consumers in the first period, and if it invests ($x_0 = 1$), the transfers of the consumers must be enough to cover the investment costs I. Second, aggregate payments over both periods must be enough to cover the entrepreneur's investment and production costs. To express these two feasibility requirements, we say that an allocation $a = (t, x)$ is *budgetary feasible* if

$$\sum_{i=1}^{n} t_{i1} \geq Ix_0 \wedge \sum_{i=1}^{n} t_{i1} + t_{i2} \geq Ix_0 + c\sum_{i} x_i. \tag{3}$$

Moreover, an entrepreneur can only produce a good to a consumer if she developed it. To express this feasibility requirement, we say that an allocation $a = (t, x)$ is *development feasible* if, whenever the good is produced for at least one consumer, the entrepreneur invested in its development:

$$\exists i : x_i = 1 \Rightarrow x_0 = 1. \tag{4}$$

This condition logically implies that if $x_0 = 0$ then $x_i = 0$ for all i.

Let the set $A \subset \mathbb{R}^{2n} \times \{0, 1\}^{n+1}$ denote the set of budgetary and development feasible allocations, ie allocations that satisfy (3) and (4).

Payoffs

Let $v = (v_1, \ldots, v_n) \in V = \{0, 1\}^n$ represent the willingness to pay of the individual consumers and let $p(v)$ represent the probability of $v \in V$. We assume that v_i's are drawn independently so that the probability over the values v other than v_i is independent of v_i. As a consequence we can write this probability as $p_i(v_{-i})$.

A feasible allocation $a \in A$ yields a consumer i with value v_i the payoff

$$u_i(a|v_i) = v_i x_i - t_{i1} - t_{i2};$$

and the entrepreneur the payoff

$$\pi(a) = \sum_{i=1}^{n} (t_{i1} + t_{i2}) - \sum_{i=1}^{n} cx_i - Ix_0 \geq 0,$$

where the inequality follows directly from the second inequality in (3), implying that any feasible allocation yields the entrepreneur a non-negative payoff.

Efficiency

In our quasi-linear setup, an output schedule $x \in X$ is *Pareto efficient* in state v if and only if it maximizes the *aggregate net surplus*

$$S(x|v) \equiv \pi(a) + \sum_{i=1}^{n} u_i(a|v_i) = \sum_{i=1}^{n} (v_i - c)x_i - Ix_0.$$

With respect to efficiency, two different types of production decisions matter: the overall investment decision x_0 and the individual production decisions x_i. Given $v_l = 0 < c < v_h = 1$, efficiency with respect to the individual allocations requires $x_i = v_i$. This yields a surplus of $\sum_i v_i(1-c) - I$.

Defining

$$\bar{n} \equiv \frac{I}{1-c}, V^0 \equiv \{v : \sum_i v < \bar{n}\}; V^1 \equiv \{v : \sum_i v \geq \bar{n}\} \text{ and } p^* \equiv \sum_{v \in V^1} p(v),$$

we can fully characterize the Pareto *efficient output schedule* $x^*(v)$ as follows. For $v \in V^0$, it exhibits $x_0^* = x_i^* = 0$ for all i. For $v \in V^1$, it exhibits $x_0^* = 1$ and $x_i^* = v_i$ for all i.[11] Note that the efficient output schedule depends on the valuations v and the ex ante probability that the project is executed is p^*.

Although transfers are immaterial for Pareto efficiency, we must nevertheless ensure that the efficient output schedule $x^*(v)$ can indeed made be part of some feasible allocation $a \in A$. In order to specify one such feasible allocation, we define the *first best* allocation $a^*(v)$ as follows. For $v \in V^1$, it exhibits $x_i = t_{i1} = v_i = 1$ and $t_{i2} = 0$. For $v \in V^0$ $a^*(v)$ is defined by $x_i = t_{i1} = x_i = t_{i1} = t_{i2} = 0$. By construction $a^*(v)$ is feasible and yields an ex ante expected gross surplus (gross of investment costs) of W^* and an expected net surplus of S^*, where

$$W^* \equiv \sum_{v \in V^1} \sum_i^n p(v) v_i (1-c) \text{ and } S^* \equiv W^* - p^* I. \tag{5}$$

We further say that an output schedule $x : V \to X$ is *development efficient* if

$$x_0(v) = 1 \Rightarrow \exists i : x_i(v) = 1. \tag{6}$$

This condition is the converse of development feasibility (4). If it does not hold, it implies the inefficiency that there is a state v in which the entrepreneur invests I but no consumer consumes the good. Although technically feasible, a schedule that is not development efficient is not Pareto efficient, since it wastes the investment $I > 0$.

For future reference, the following lemma summarizes these considerations.

Lemma 1 *The first best allocation $a^*(v)$ is feasible and exhibits an output schedule that is development efficient. It yields an expected net surplus of S^*.*

[11]For $\sum_i v = \bar{n}$, the output schedule $x_0^* = x_i^* = 0$ is also efficient, but this is immaterial (and can only arise for the non-generic case that I is a multiple of $1-c$).

Mechanisms

We next turn to mechanisms. A *mechanism* Γ is a set of rules between the entrepreneur and the n consumers that induces a game between them. Its outcome is an allocation $a \in A$ with subsequent payoffs $\pi(a)$ and $u_i(a|v_i)$. We follow the idea that the crowdfunding platform, as the mechanism designer, runs the mechanism; it credibly commits to enforce the rules of the game which the mechanism specifies.

A *direct mechanism* is a function $\gamma : V \to A$, which induces the following game. First, consumers simultaneously and independently send a report v_i^r about their values to the platform. Based on the collected reports v^r and in line with the rules γ, the platform collects the funds $T_1 = \sum_i t_{i1}(v^r)$ from the consumers and transfers it to the entrepreneur together with the recommendation $x_0(v^r)$ about whether to invest I. To capture the moral hazard problem, we explicitly assume that the platform cannot coerce the entrepreneur into following the recommendation. That is, the entrepreneur is free to follow or reject it. If, however, the entrepreneur follows the recommendation, the platform enforces the production schedule $x(v^r) = (x_1(v^r), \ldots, x_n(v^r))$ and the transfers $t_{i2}(v^r)$. If the entrepreneur does not follow the recommendation, but runs, then individual production schedules are 0, and no second period transfers flow, ie $x_i = t_{i2} = 0$. Moreover, consumers forfeit their first period transfers t_{i1}.

A direct mechanism γ is *incentive compatible* if its induced game as described above has a perfect Bayesian equilibrium in which 1) consumers are *truthful* in that they reveal their values honestly, ie $v_i^r = v_i$, and 2) the entrepreneur is *obedient* in that she follows the recommendation, ie $x_0 = x_0(v^r)$.

To formalize the notion of truthful revelation, we define

$$X_i(v_i) \equiv \sum_{v_{-i} \in V_{-i}} x_i(v_i, v_{-i}) p_i(v_{-i});$$

and

$$T_i(v_i) \equiv \sum_{v_{-i} \in V_{-i}} (t_{i1}(v_i, v_{-i}) + t_{i2}(v_i, v_{-i})) p_i(v_{-i}).$$

Consequently, we say that a direct mechanism γ is *truthful* if

$$v_i X_i(v_i) - T_i(v_i) \geq v_i X_i(v_i') - T_i(v_i') \text{ for all } i \in I \text{ and } v_i, v_i' \in V_i. \quad (7)$$

To formalize the notion of obedience, we define for a direct mechanism γ the set $\mathcal{T}_1$ as the set of possible aggregate first period transfers which the mechanism can induce conditional on recommending investment:

$$\mathcal{T}_1 \equiv \{T_1 | \exists v \in V : \sum_{i=1}^{n} t_{i1}(v) = T_1 \wedge x_0(v) = 1\}.$$

Given this set we define for any $T_1 \in \mathcal{T}_1$ the set $V(T_1)$ which comprises all states that induce a recommendation to invest together with a total transfer T_1:

$$V(T_1) \equiv \{v \in V | x_0(v) = 1 \wedge \sum_i t_{i1}(v) = T_1\}.$$

Upon receiving a recommendation to invest, the entrepreneur has received some transfer $T_1 \in \mathcal{T}_1$ and has a belief $p(v|T_1)$ that the state is v. These beliefs are Bayes' consistent whenever

$$p(v|T_1) \equiv \begin{cases} \frac{p(v)}{\sum_{v' \in V(T_1)} p(v')} & \text{if } v \in V(T_1); \\ 0 & \text{otherwise.} \end{cases}$$

We say that a direct mechanism γ is *obedient* if for any $T_1 \in \mathcal{T}_1$ and after obtaining the recommendation to invest, $x_0 = 1$, the entrepreneur is, given her updated belief $p(v|T_1)$, better off investing than taking the money and run:

$$\sum_{v \in V} \sum_{i=1}^{n} p(v|T_1)(t_{i2}(v) - cx_i(v)) \geq I, \text{ for all } T_1 \in \mathcal{T}_1. \tag{8}$$

We say that a direct mechanism is incentive compatible if and only if it is truthful and obedient.

Note that crowdfunding schemes, which hand all transfers to the entrepreneur upfront, exhibits $t_{i2}(v) = 0$ for all i and v. Such schemes necessarily violate condition (8) for *any* $T_1 \in \mathcal{T}_1$. This formally confirms are informal discussion that such schemes are unable to handle the extreme kind of moral hazard problems that we consider here.

By its nature, participation in the crowdfunding mechanism is voluntary so that it must yield the consumers and the entrepreneur at least their outside option. Taking these outside options as 0, the entrepreneur's participation is not an issue, because, as argued, any feasible allocation yields the entrepreneur a non-negative payoff. In contrast, a consumer's participation in an incentive compatible direct mechanism is *individual rational* only if

$$v_i X_i(v_i) - T_i(v_i) \geq 0 \text{ for all } i \in I \text{ and } v_i \in V_i. \tag{9}$$

We say that a direct mechanism γ is *feasible*, if it is incentive compatible and individual rational for each consumer.[12] A feasible direct mechanism yields consumer i with valuation v_i the utility

$$u_i(v_i) \equiv v_i X_i(v_i) - T_i(v_i). \tag{10}$$

and the entrepreneur an expected payoff

$$\pi = \sum_{v \in V} p(v)\pi(\gamma(v)). \tag{11}$$

We say that two feasible direct mechanisms $\gamma = (t, x)$ and $\gamma' = (t', x')$ are *payoff-equivalent* if they lead to identical payoffs to each consumer i:

$$\sum_{v_{-i} \in V_{-i}} p(v_{-i}) u_i(\gamma(v), v_i) = \sum_{v_{-i} \in V_{-i}} p(v_{-i}) u_i(\gamma'(v), v_i) \ \forall i, v_i;$$

and the entrepreneur:

$$\sum_{v \in V} p(v)\pi(\gamma(v)) = \sum_{v \in V} p(v)\pi(\gamma'(v)).$$

Implementability

An *allocation function* $f : V \to A$ specifies for any value profile v an allocation $a \in A$. It is *implementable* if there exists a mechanism Γ such that the induced game has a perfect Bayesian equilibrium outcome in which the induced allocation coincides with $f(v)$ for every $v \in V$. In this case, we say Γ *implements* f.

Likewise, an *output schedule* $x : V \to X$ specifies for any value profile v an output schedule $x \in X$. It is *implementable* if there exists a mechanism Γ such that the induced game has a perfect Bayesian equilibrium outcome in which the induced output coincides with $x(v)$ for every $v \in V$. In this case, we say Γ implements output schedule $x(\cdot)$.

By the dynamic revelation principle, an allocation function $f(\cdot)$ is implementable if and only if there exists a feasible direct mechanism γ with $\gamma(v) = f(v)$ for any $v \in V$. Likewise, an output schedule $x(\cdot)$ is implementable if and only if there exists

[12] This implicitly assumes that the mechanism has "perfect consumer reach" in that every consumer is aware and can participate in the mechanism. As an extension that yields important additional insights, Subsection 6.2 studies the effect of imperfect consumer reach.

a direct mechanism $\gamma = (x_\gamma, t_\gamma)$ such that $x_\gamma(v) = x(v)$ for any $v \in V$. The revelation principle as usual motivates our focus on incentive compatible direct mechanisms and allows us to demonstrate the following result.

Proposition 1 *The efficient output schedule $x^*(v)$ is, in general, not implementable.*

The main driver behind the proposition's inefficiency result is a tension between the entrepreneur's budget constraint and her moral hazard problem. For consumers to make sure that the entrepreneur realizes her project, it does not suffice to give her simply the required amount I to invest. Due to the moral hazard problem, she must also be given an incentive to actually invest this money. The proposition shows that, in general, the solution to one problem precludes the other. As shown in the proof, this occurs in particular, when the investment I is "close" to the potential revenue of the project.

The proposition raises the question what output schedules are implementable. To answer this question we have to investigate the mechanism design problem further. The following lemma shows that with respect to development efficient allocations, we may reduce the class of feasible direct mechanisms further.

Lemma 2 *If $\gamma = (t, x)$ is feasible and x is development-efficient then there is a feasible and pay-off equivalent direct mechanism $\gamma' = (t', x)$ with*

$$\sum_i t'_{i1}(v) = I x_0(v), \forall v \in V. \tag{12}$$

The lemma implies that with respect to development-efficient mechanisms there is no loss of generality in restricting attention to feasible direct mechanisms that satisfy (12). Hence, we only need to consider mechanisms that give the entrepreneur exactly the amount I if the entrepreneur is to develop the product. This also means that the lemma makes precise the suggestion of the previous section that a mechanism should provide the entrepreneur with the minimal amount of information for reducing demand uncertainty; she should effectively only be told that the demand of consumers ensures that the project has a positive NPV, but not more. The main step in proving this result is to show that obedience remains satisfied when we replace different aggregate levels of first period payments by a single one.[13]

[13]The lemma fails for specific development-inefficient mechanisms so that we cannot dispense with the restriction to development-efficient mechanisms.

The lemma simplifies the mechanism design problem in two respects. First, under condition (12), condition (3) reduces to

$$\sum_{i=1}^{n} t_{i2} \geq c \sum_{i} x_i. \tag{13}$$

Second, under condition (12), we have $\mathcal{T}_1 = \{I\}$ so that the obedience constraint (8) must only be respected with regard to I:

$$\sum_{v \in V} \sum_{i=1}^{n} p(v|I)(t_{i2}(v) - cx_i(v)) \geq I. \tag{14}$$

5 Second-best crowdfunding schemes

In this section we characterize second best mechanisms $\gamma^{sb} = (x^{sb}, t^{sb})$ that maximize aggregate surplus in the presence of demand uncertainty and moral hazard. We are especially interested in determining and understanding the circumstances under which these second best mechanisms do not implement the efficient output schedule x^*.

Recall that a feasible direct mechanism γ yields a surplus of

$$\sum_{v \in V} p(v) S(x(v)|v) = \sum_{v \in V} p(v) \left[\sum_{i}^{n} (v_i - c) x_i(v) - I x_0(v) \right]. \tag{15}$$

Clearly γ^{sb} cannot yield more than the surplus S^* that is generated under the efficient output schedule x^*. Indeed, Proposition 1 showed that, in general, we cannot guarantee that γ^{sb} attains S^*. In this case, the second best output schedule x^{sb} does not coincide with x^* and will display distortions.

As γ^{sb} is necessarily development-efficient, we can find γ^{sb} by maximizing (15) subject to the constraints (7), (9), (12), (13), and (14), because these constraints characterize the set of implementable allocation functions that are development-efficient.

A straightforward consideration of this maximization problem yields the following partial characterization of γ^{sb}:

Lemma 3 *The individual rationality constraint consumers with the high value $v_i = 1$ does not restrict the second best mechanism γ^{sb}. The second best mechanism exhibits $x_i(0, v_{-i}) = 0$, $X_i(0) = 0$, and $T_i(0) = 0$.*

It follows from the previous lemma that the second best mechanism γ^{sb} is a solution to the problem

$$\max_{x(.),t(.)} \quad \sum_{v\in V} p(v)\left[\sum_{i}^{n}(v_i - c)x_i(v) - Ix_0(v)\right]$$

$$\text{s.t.} \quad T_i(1) = X_i(1) \text{ for all } i \in I \tag{16}$$

$$\sum_{v\in V}\sum_{i=1}^{n} p(v|I)(t_{i2}(v) - cx_i(v)) \geq I \tag{17}$$

$$T_i(0) = 0 \text{ for all } i \in I \tag{18}$$

$$\sum_{i=1}^{n} t_{i1}(v) = Ix_0(v) \tag{19}$$

$$\sum_{i=1}^{n} t_{i2}(v) \geq \sum_{i} cx_i(v) \tag{20}$$

$$x_i(v) = 1 \Rightarrow x_0(v) = 1 \tag{21}$$

$$x_i(0, v_{-i}) = 0, \forall v_{-i} \in V_{-i}. \tag{22}$$

Recalling that p^* represents the ex ante probability that the project is executed under the efficient schedule x^*, we obtain the following result.

Proposition 2 *The efficient output schedule x^* is implementable if and only if $W^* \geq 2p^*I$.*

Proposition 2 makes precise the parameter constellation under which the first best x^* is implementable: only if the efficient production schedule x^* generates a surplus that exceeds twice the ex ante expected investment costs.

As argued before, the main driver behind the inefficiencies is a tension between the entrepreneur's budget constraint and her moral hazard problem. For consumers to make sure that the entrepreneur realizes her project, it does not suffice to give her simply the required amount I to invest. Due to the moral hazard problem, she must also be given an incentive to actually invest this money. As the proposition shows, this requires consumers to pay the entrepreneur the required investment I twice. Once in order to finance the good's development and, once more, in order to prevent the entrepreneur from simply taking this money and run. To consumers, realizing the project is therefore only worthwhile if the project's revenue recovers the investment I twice.

Effectively, the proposition shows that the combination of the entrepreneur's budget constraint and her moral hazard problem lead to a duplication of the investment costs. This prevent the first best outcome to be attainable if the expected gross surplus W^* is too small.

Whenever the ex ante gross surplus does not cover for the expected investment costs twice, the efficient output schedule, x^*, is not implementable so that the second best output schedule x^{sb} does not coincide with x^*. We next derive a partial characterization of the second best and, more importantly, characterize the type of efficiencies it exhibits.

Proposition 3 *For $W^* < 2p^*I$, the constrained efficient output schedule x^{sb} exhibits $x_i^{sb}(v) = v_i$ whenever $x_0^{sb}(v) = 1$ and $x_0^{sb}(v) = 0$ whenever $x_0^*(v) = 0$. Moreover, $x_0^{sb}(v) = 1$ whenever $\sum v_i > 2I/(1-c)$.*

The first part of the proposition shows that the constrained efficient output schedules are only distorted with respect to the investment decision but not to the individual assignments. The second part of the proposition shows that the second best output schedule is distorted downwards rather than upwards. The final part shows that at most the allocations for which aggregate valuations lie in the range between $I/(1-c)$ and $2I/(1-c)$ are downward distorted. Exactly which of these are distorted downwards depends on the specific parameter constellation.

6 Interpretation and Discussion

This section interprets the optimal direct mechanisms as derived in the previous sections and relate them to crowdfunding schemes in practise. It further discusses extensions and robustness of the results.

6.1 Relation to crowdfunding in practise

A first notable feature of optimal direct mechanisms is that they explicitly condition the entrepreneur's investment decision on the aggregate reported valuations rather than each consumer's report individually. This result confirms the intuitive ideas developed in Section 3. It is not only consistent with the "all-or-nothing" pledge schemes of the popular reward-crowdfunding platform Kickstarter, but also many others such as the music crowdfunding platforms Sellaband, which was already established in 2006, and PledgeMusic. We can interpret such schemes as indirect mechanisms that implement such conditional investment optimally.

Interestingly, the “keep-what-you-raise” model, where pledges are triggered even if the target level is not reached, is an alternative scheme that is popular for platforms that are less orientated towards for-profit causes such as the donation platform GoFundMe. Indiegogo, which markets itself as both a for-profit and non-profit crowdfunding platform, lets the project’s initiator decide between the two options. Anecdotal evidence suggests that for-proft projects are more prone to select the “all-or-nothing” scheme.

A second feature of optimal direct mechanisms is that they do not exhibit negative transfers. Hence, at no point in time the entrepreneur pays the consumers any money. In particular, the entrepreneur does not share any of her revenue or profits after the investment. Consequently, optimal direct mechanisms do not turn consumers into investors. This feature is consistent with reward-crowdfunding in practise. Independently of the entrepreneur’s finale revenues, a crowdfunding consumer receives only a fixed, non-monetary reward for his pledged contribution. Reward-crowdfunding schemes such as Kickstarter actually explicitly prohibit financial incentives like equity or repayment to crowdfunders.[14] The next subsection points out however that optimal mechanism may require negative transfers if the consumer reach of the platform is limited.

A third feature of optimal direct mechanisms is the use of deferred payments to prevent moral hazard. Some but definitely not all crowdfunding platforms do so. For instance, PledgeMusic, a reward-crowdfunding site specialized in raising funds for recordings, music videos, and concerts, explicitly states on its Website that it uses a sophisticated scheme with deferred payouts to prevent fraud.[15] For its “direct-to-fan campaigns”, which represent its reward-crowdfunding schemes, it actually uses three payout phases: For a project that exceeds its target level, it pays 75% of the target level (minus commissions) directly after the crowdfunding stage ends successfully.

[14] See `https://www.kickstarter.com/rules?ref=footer` (last retrieved 22.7.2015)

[15] See `http://www.pledgemusic.com/blog/220-preventing-fraud` (last retrieved 20.07.2015)

The remaining 25% of the target level is paid out upon delivery of the digital album, while all funds in excess of the target level are paid out only upon successful delivery of all other types of rewards.

The final notable feature of optimal direct mechanisms is that they provide only information about whether the sum of pledges exceeds the target and not the total sum of pledges. In line with Lemma 2 any additional information is not needed to implement (constrained) efficient outcomes and schemes that provide more information may exacerbate the moral hazard problem. Current crowdfunding platforms do not reflect this feature. Currently all crowdfunding platforms are fully transparent and announce publicly the total amount of pledges rather than just whether the target level was reached.

Despite of explicit concerns by the press, practitioners, and also the crowdfunding platforms themselves, anecdotal evidence suggests that moral hazard is currently not a major issue for crowdfunding platforms as actual cases of fraud are extremely rare.[16] As we discuss in the next subsection, one reason for this is the limited consumer reach of current crowdfunding schemes. Due to the fact that crowdfunding is still a rather new phenomenon and does not reach all potential consumers, a successful entrepreneur can expect a substantial after-crowdfunding market and sell her products to consumers who did not participate in crowdfunding. The entrepreneur's prospect to sell her goods to non-crowdfunding consumers acts as a substitute for deferred payments and, therefore, mitigates moral hazard. As crowdfunding becomes more popular and the after-crowdfunding market decreases, this substitution effect diminishes. We investigate this aspect more closely in the next subsection.

6.2 Consumer reach and Crowdinvestors

In our formal analysis, consumers could only acquire the product by participating in the mechanism and, by assumption, the mechanism is able to reach every potential consumer. Given this latter assumption, the assumption that consumer can only acquire the product through the mechanism is, by the revelation principle, without loss

[16]We are aware of only three campaigns on Kickstarter that indicated fraudulent behavior of which one was stopped before the crowdfunding campaign was completed.

of generality. This changes however when, for some exogenous reason, a mechanism's consumer reach is imperfect in that not all consumers can participate in it. In practise this seems a reasonable concern, because a share of consumers may, for example, fail to notice the crowdfunding scheme, do not have access to the internet, or will only arrive in the market after the product has been developed. Hence, a relevant extension of our framework is to consider mechanisms, which, for some exogenous reason, have an imperfect consumer reach.

Consider first a model with imperfect consumer reach, in which only a share of $\beta \in (0, 1)$ can take part in the mechanism. Already the pure proportional case that a consumer's ability to participate is independent of his valuation, yields new insights.

For the pure proportional case, the crowdfunding scheme is still able to elicit perfectly consumer demand; a pledge by $\tilde{n}$ consumers means that there are in fact $n_1 = \tilde{n}/\beta$ who value the product. Consequently, investment is efficient if and only if

$$\tilde{n}/\beta \geq I/(1-c) \Rightarrow \tilde{n} \geq \bar{n}(\beta) \equiv \beta I/(1-c).$$

It is straightforward to see that the previous analysis still applies when we factor in β. In particular, the efficient output scheme is implementable for $W^* \geq 2p^* I\beta$.[17]

Even though our analysis readily extends to this proportional case, the interesting economic effect arises that *consumers become active investors* when the share of crowdfunding consumers β is small. To see this, note that, because the entrepreneur needs the amount I to develop the product, the (average) first period transfer of a pledging consumer needs to be at least $I/\tilde{n}$. When β is small in the sense that $\bar{n}(\beta)$ is smaller than 1, it follows that for $\tilde{n}$ close to $\bar{n}(\beta)$, the consumer's first period transfer *exceeds* his willingness to pay. Individual rationality then implies that the second period transfer to the consumer must be *negative* in order to make it worthwhile for the consumer to participate.

Since a negative second period transfer means that the entrepreneur returns part of his first period contribution after the project is executed, such transfers imply that

[17] This "proportionality" property holds because the derived efficient scheme extracts all rents from consumers and the entrepreneur can implement the efficient outcome by using the scheme as derived and set a price $p = 1$ to the $(1-\beta)n$ consumers who can only participate after the good has been developed.

the consumer effectively becomes an investor in the usual sense that he receives a monetary return on his initial layout. Hence, with limited consumer reach, efficient crowdfunding schemes may require consumers to become actual investors.

As noted, reward-crowdfunding schemes such as Kickstarter explicitly prohibit financial incentives like equity or repayment to crowdfunders. Our formal analysis confirms that this is indeed not needed if the investment I is small compared to the number of crowdfunding consumers, but for large investments and crowdfunding schemes with a relatively small consumer reach, such restrictions may matter.[18] Probably the main reason that reward-crowdfunding platforms do not allow financial incentives is due to regulation. Without any monetary flows from the entrepreneur to crowdfunders, crowdfunding in the US is not an investment vehicle and does therefore not fall under SEC regulation.

6.3 Elastic demand

Our formal model assumes that consumers' valuations are of a binary nature. Consumers either do not value the good ($v = 0$) or value it at the same positive amount ($v = 1$). This assumption yields an inelastic demand structure and, more importantly, a framework in which demand uncertainty expresses itself only concerning the question whether the entrepreneur should invest or not. This enabled us to clearly illustrate crowdfunding as an economic institution that creates economic value by reducing demand uncertainty and, thereby, identify the projects with a positive NPV. Moreover, it allowed us to clarify that the "all-or-nothing"-pledge system of common crowdfunding platforms is in fact a crucial feature that enables the screening of positive NPV projects.

An obvious modeling extension is to consider consumer valuations that are drawn

[18] Ordanini et al. (2011) report the case of Cameesa, a Chicago based clothing company which in 2008 introduced an "all-or-nothing" crowdfunding model, but also shared revenue with its crowdfunders. The company accepted pledges with a minimum of $10 from "Supporters" for the production of T-shirts designs and a target level of $500, which cumulative pledges needed to reach before the T-shirt was produced. Any Supporter who pledged in a failing design got their money back, while Supporters of a successful design not only obtained the shirt, but also shared in some of the revenue of its future sales. (see `http://www.cnet.com/news/cameesa-a-threadless-where-customers-are-also-investors/`, last retrieved 22.7.2015).

from more than two states or with different supports. In this case, aggregate demand will be elastic and demand uncertainty expresses itself not only in the question whether to invest but also in the question what price (or pledge level) to set. Hence, resolving demand uncertainty also allows the entrepreneur to pick the right price. Economist (2010) reports of a concrete example of a book publisher planning to funding the republication of a sold-out book: "his efforts to tease out lenders' price sensitivity from previous Kickstarter projects showed that a $50 contribution was the most popular amount. It also proved the largest dollar component for the highest-grossing Kickstarter projects." Because the current paper focuses on economic efficiency rather than revenue extraction, we only mention this ability of crowdfunding schemes without exploring this idea formally.

7 Conclusion

Reward-crowdfunding severs the traditional separation of finance and marketing and thereby fundamentally changes the organizational model of entrepreneurship. This new model has the clear economic advantage over the traditional one that it elicits demand information directly from consumers in an incentive compatible way. It thereby allows a better screening of positive NPV projects.

Due to the free friding problem that individual crowdfunders have reduced incentives to monitor as compared to the crowd as a whole, the threat of entrepreneurial moral hazard may potentially counter this effect.

Posing the subsequent economic problem as one of optimal mechanism design and interpreting crowdfunding platforms as institutions that execute the mechanism, offers an explanation for some salient features of current reward-crowdfunding platforms. Most importantly, the popularity of "all-or-noting" pledging schemes. Yet. also the feature that reward-crowdfunding platforms do not ask their crowdfunders to become genuine investors who obtain some share of the project's revenues is consistent with our analysis if such platform reach enough consumers.

Despite their effectiveness in eliciting demand information, the moral hazard problem may prevent the implementation of fully efficient outcomes in that efficiency is sustainable only if a project's ex ante expected gross return exceeds its ex ante expected investment costs at least twice. Constrained efficient mechanisms exhibit underinvestment.

Whereas current crowdfunding platforms reflect the properties of optimal mechanisms that deal with demand uncertainty, they do not seem to reflect the properties of mechanisms that deal with moral hazard optimally. This confirms anecdotal evidence that moral hazard in crowdfunding is currently rare, despite popular warnings of the opposite. We attribute this to the prospect of a successful entrepreneur to sell her goods also to non-crowdfunding consumers, because this prospect acts as a direct substitute for deferred payments. As the popularity of crowdfunding grows, this effect declines and the problem of entrepreneurial moral hazard may require platforms to follow the example of PledgeMusic to introduce deferred payouts or, as also suggested by our analysis, even limit the platform's transparency.

Because crowdfunding schemes by themselves are, in the presence of moral hazard, unable to attain efficiency in general, we point out that the main conclusion to be drawn from our analysis is broader. Indeed, because the main economic advantages of traditional venture capitalists and crowdfunding lie in different dimensions, the two financing models are complements rather than substitutes. In other words, we expect a convergence of the two models of entrepreneurship, especially, as the problem of moral hazard in crowdfunding rises — which as explained we expect when crowdfunding becomes more and more main stream.[19] Current regulatory policies measures such as the US JOBS Act and its implementation in SEC (2015) will make such mixed forms of crowdfunding and more traditional venture capitalism easier to develop so that one can take advantage of their respective strengths. The website of the crowdfunding platform Rockethub already explicitly mentions this possible effect of the JOBS Act.[20]

[19]As mentioned in footnote 5, an explicit example of such potential convergence is the case of Pebble, which first obtained VC backing after its crowdfunding campaign.

[20]See `http://www.rockethub.com/education/faq#jobs-act-index` (last retrieved 22.7.2015).

Appendix

This appendix collects the formal proofs.

Proof of Lemma 1: Follows directly from the text Q.E.D.

Proof of Proposition 1: It is sufficient to demonstrate the result in a specific parameterization of the model. Let $I = n - 1/2$ and $c = 0$ and let $\mathbf{1}^n$ denote the vector $(1, \ldots, 1) \in \mathbb{R}^n$.

Since $\bar{n} = I/(1-c) = n - 1/2$, the efficient output schedule exhibits $x_0 = x_i = 0$ for $v \neq \mathbf{1}^n$, and $x_0 = x_i = 1$ for $v = \mathbf{1}^n$. We show by contradiction that a feasible direct mechanism that implements the efficient output schedule $x^*(v)$ does not exist.

For suppose to the contrary that such a direct mechanism does exist, then the entrepreneur's Bayes' consistent beliefs after a recommendation to invest, $x_0 = 1$, is degenerated, because $x_0^*(v)$ equals 1 only if $v = \mathbf{1}^n$. Hence, the entrepreneur puts probability 1 on $v = \mathbf{1}^n$. Consequently, (8) writes after multiplying by $p(\mathbf{1}^n)$ as

$$\sum_{i=1}^{n} t_{i2}(\mathbf{1}^n)p(\mathbf{1}^n) \geq Ip(\mathbf{1}^n). \tag{23}$$

Since $x_0(1^n) = 1$ condition (3) implies after multiplying with $p(\mathbf{1}^n)$ that

$$\sum_{i=1}^{n} t_{i1}(\mathbf{1}^n)p(\mathbf{1}^n) \geq Ip(\mathbf{1}^n). \tag{24}$$

Note further that (3) for each $v \neq \mathbf{1}^n$ implies

$$\sum_{i=1}^{n} t_{i1}(v) + t_{i2}(v) \geq 0 \tag{25}$$

Multiplying with $p(v)$ and adding over all $v \neq \mathbf{1}^n$ yields

$$\sum_{v \neq \mathbf{1}^n} \sum_{i=1}^{n} (t_{i1}(v) + t_{i2}(v))p(v) \geq 0 \tag{26}$$

Combining (23), (24), and (26) yields

$$\sum_{i} \sum_{v \in V} (t_{i1}(v) + t_{i2}(v))p(v) \geq 2Ip(\mathbf{1}^n) = (2n-1)p(\mathbf{1}^n), \tag{27}$$

where the equality uses $I = n - 1/2$.

We now show that (27) contradict the consumers' individual rationality. Since $X_i(0) = 0$, (9) for $v_i = 0$ implies after a multiplication by $p_i(0)$ for each i

$$\sum_{v_{-i} \in V_{-i}} (t_{i1}(0, v_{-i}) + t_{i2}(0, v_{-i}))p(0, v_{-i}) \leq 0. \tag{28}$$

Summing over i it follows

$$\sum_i \sum_{v_{-i}\in V_{-i}} (t_{i1}(0,v_{-i}) + t_{i2}(0,v_{-i}))p(0,v_{-i}) \leq 0. \tag{29}$$

Likewise, since $X_i(1) = p_i(\mathbf{1}^{n-1})$, (9) for $v_i = 1$ implies after a multiplication with $p_i(1)$ that for each i

$$\sum_{v_{-i}\in V_{-i}} (t_{i1}(1,v_{-i}) + t_{i2}(1,v_{-i}))p(1,v_{-i}) \leq p(\mathbf{1}^n). \tag{30}$$

Summing over i yields

$$\sum_i \sum_{v_{-i}\in V_{-i}} (t_{i1}(1,v_{-i}) + t_{i2}(1,v_{-i}))p(1,v_{-i}) \leq p(\mathbf{1}^n)n. \tag{31}$$

Combining (29) and (31) yields

$$\sum_i \sum_{v\in V}(t_{i1}(v) + t_{i2}(v))p(v) \leq p(\mathbf{1}^n)n. \tag{32}$$

But since $2n-1 > n$, this contradicts (27). Q.E.D.

Proof of Lemma 2: Fix $\gamma = (t,x)$ and define for each v,

$$K(v) \equiv \sum_i t_{i1}(v) - Ix_0(v).$$

Then since $\gamma = (t,x)$ is feasible, it satisfied (3) and it therefore holds $K(v) \geq 0$ for all $v \in V$. For any state v, let $n(v) \equiv \sum_i x_i(v)$ represent the total number of consumers with $x_i = 1$. For any state v with $x_0(v) = 0$, define $t'_{i1}(v) = 0$ and $t'_{i2}(v) = t_{i1}(v) + t_{i2}(v)$. For $x_0(v) = 1$ define $t'_{i1}(v) = t_{i1}(v) - x_i(v)K(v)/n(v)$ and $t'_{i2}(v) = t_{i2}(v) + x_i(v)K(v)/n(v)$. Since x is development efficient, it holds $n(v) > 0$ if and only if $x_0(v) = 1$. Hence, the transformed transfer schedule t' is well-defined and completely described. By construction, we have $\sum_i t'_{i1}(v) = 0$ for any v with $x_0(v) = 0$ and $\sum_i t'_{i1}(v) = \sum_i t_{i1}(v) - x_i(v)K(v)/n(v) = \sum_i t_{i1}(v) - K(v) = I$ for any v with $x_0(v) = 1$. Hence, the allocation $(t'(v), x(v))$ satisfies (12). Because the allocation $(t(v), x(v))$ is development feasible, also the allocation $(t'(v), x(v))$ is development feasible. Moreover, from $t'_{i1}(v) + t'_{i2}(v) = t_{i1}(v) + t_{i2}(v)$ it follows that (t', x) is also budgetary feasible, truthtelling, and individual rational for consumers, given that (t,x) is so by assumption.

In order to show that (t', x) is feasible, it only remains to show that it is obedient, i.e., satisfies (8). To show this, define for $T_1 \in \mathcal{T}$

$$P(T_1) = \sum_{v \in V(T_1)} p(v),$$

Now since, $\gamma = (t, x)$ is obedient by assumption, (8) holds for any $T_1 \in \mathcal{T}$ and, since $t'_{i2}(v) \geq t_{i2}(v)$ for any v, it follows after a further multiplication by $P(T_1)$ that

$$\sum_{v \in V} \sum_{i=1}^{n} p(v|T_1) P(T_1)(t'_{i2}(v) - cx_i(v)) \geq I \cdot P(T_1). \tag{33}$$

By definition of $p(v|T_1)$ we have $p(v|T_1)P(T_1) = p(v)\mathbf{1}_{v \in V(T_1)}$, where $\mathbf{1}_A$ is the indicator function which is 1 if the statement A is true and 0 otherwise. Thus we may rewrite the former inequality as

$$\sum_{v \in V} \sum_{i=1}^{n} p(v)\mathbf{1}_{v \in V(T_1)}(t'_{i2}(v) - cx_i(v)) \geq I \cdot P(T_1). \tag{34}$$

This inequality holds for any $T_1 \in \mathcal{T}_1$. Summing over all $T_1 \in \mathcal{T}_1$ we obtain

$$\sum_{T_1 \in \mathcal{T}_1} \sum_{v \in V} \sum_{i=1}^{n} p(v)\mathbf{1}_{v \in V(T_1)}(t'_{i2}(v) - cx_i(v)) \geq \sum_{T_1 \in \mathcal{T}_1} I \cdot P(T_1), \tag{35}$$

which we may rewrite as

$$\sum_{v \in V} \sum_{i=1}^{n} p(v)\mathbf{1}_{v \in V'(I)}(t'_{i2}(v) - cx_i(v)) \geq I \cdot P(\cup_{T_1 \in \mathcal{T}_1} T_1), \tag{36}$$

where V' and P' are the respective sets V and probability P under the mechanism γ'. Since for any $T_1 \in \mathcal{T}_1$ and v such that $x_0(v) = 1$, we have by construction that $\sum_i t'_{i1}(v) = I$, we may rewrite this latter inequality as

$$\sum_{v \in V} \sum_{i=1}^{n} p(v)\mathbf{1}_{\{x_0(v)=1 \wedge \sum_i t'_{i1}(v)=I\}}(t'_{i2}(v) - cx_i(v)) \geq IP'(I), \tag{37}$$

but this is equivalent to

$$\sum_{v \in V} \sum_{i=1}^{n} p'(v|I)(t'_{i2}(v) - cx_i(v)) \geq I \cdot P'(I), \tag{38}$$

and shows that $\gamma' = (t', x)$ is obedient. To complete the proof note that since $t'_{i1}(v) + t'_{i2}(v) = t_{i1}(v) + t_{i2}(v)$, the feasible direct mechanism $\gamma' = (t', x)$ is payoff equivalent to original mechanism $\gamma = (t, x)$. Q.E.D.

Proof of lemma 3: The first statement follows because, as usual, the incentive constraint of a consumer with value $v_i = 1$ and the individual rationality of a consumer with value $v = 0$ imply the individual rationality of a consumer with value $v = 1$.

To see $x_i(0, v_{-i}) = 0$, note that if not, then $x_i(0, v_{-i}) = 1$. But then lowering it to 0 raises the efficiency objective by $p(0, v_{-i})c$, while relaxing all other constraints. The statement $X_i(0) = 0$ follows as a corollary.

To see $T_i(0) = 0$, note that if not then we raise all $t_{i2}(0, v_{-i})$ and $t_{i2}(1, v_{-i})$ by $\varepsilon > 0$. This relaxes constraints and does not affect objective.

To see $T_i(1) = X_i(1)$. If not then raise all $t_{i2}(1, v_{-i})$ by $\varepsilon > 0$. This relaxes constraints and does not affect objective. Q.E.D.

Proof of Proposition 2: Define

$$p^*(v) \equiv \begin{cases} p(v)/p^* & \text{if } x_0^*(v) = 1; \\ 0 & \text{otherwise,} \end{cases}$$

where we recall that p^* is the ex ante probability that the entrepreneur invests under the efficient production schedule x^*. The condition $W^* \geq 2p^*I$ is then equivalent to

$$\sum_{v \in V} \sum_i p^*(v) v_i (1 - c) \geq 2I. \tag{39}$$

We first proof that under condition (39) the first best is implementable by constructing a transfer schedule t^* such that the direct mechanism $\gamma^* = (t^*, x^*)$ is incentive compatible and therefore implements x^*. For any v such that $x_0^*(v) = 0$, set $t_{i1}^*(v) = t_{i2}^*(v) = 0$. For any v such that $x_0^*(v) = 1$, let $\bar{x}^*(v) \equiv \sum_i x_i^*(v) > 0$ represents the efficient number of goods to be produced in state v.[21] Set $t_{i1}^*(v) = x_i^*(v)I/\bar{x}^*(v)$ and $t_{i2}^*(v) = x_i^*(v)(1 - I/\bar{x}^*(v))$.

We show that the resulting direct mechanism γ^* is feasible, ie. satisfies (3), (7), (8), and (9) for each $v \in V$.

To show (3) for v such that $x_0^*(v) = 0$, note that $\sum_i t_{i1}^*(v) = 0 = Ix_0^*(v)$, and that $\sum_i t_{i1}^*(v) + t_{i2}^*(v) = 0 = Ix_0^*(v) + c\sum_i x_i^*(v)$, since $x_i^*(v) = 0$ for all i whenever $x_0^*(v) = 0$. To show (3) for v such that $x_0^*(v) = 1$, note that $\sum_i t_{i1}^*(v) = \sum_i x_i^*(v)I/\bar{x}^*(v) = I = Ix_i^*(0)$ and $\sum_i t_{i1}^*(v) + t_{i2}^*(v) = \sum_{\{i:x_i^*(v)=1\}}(t_{i1}^*(v) + t_{i2}^*(v)) + \sum_{\{i:x_i^*(v)=0\}}(t_{i1}^*(v) + t_{i2}^*(v)) = \sum_{\{i:x_i^*(v)=1\}} 1 + \sum_{\{i:x_i^*(v)=0\}} 0 = \sum_i v_i \geq I + \sum_i cv_i = Ix_0^*(v) + c\sum_i x_i^*(v)$,

[21] $\bar{x}^*(v)$ is greater than 0, since $x_0^*(v) = 1$ and x^* is development-efficient.

where the inequality holds because $x^*(0) = 1$ is efficient by assumption so that $\sum_i v_i \geq I + \sum_i cv_i$.

To show (9) and (7) note that x^* exhibits $x_i^*(0) = 0$ so that $X_i^*(0) = 0$ and $T_i^*(0) = 0$. Moreover, $X_i^*(1) \geq 0$ and $T_i^*(1) \geq 0$. For $v_i = 0$, it therefore follows $v_i X_i^*(v_i) - T_i^*(v_i) = 0 \cdot X_i^*(0) - T_i^*(0) = 0 \leq -T_i^*(1) = 0 \cdot X_1^*(1) - T_i^*(1)$ so that (7) and (9) are satisfied for $v_i = 0$. To see that (9) and (7) are also satisfied for the other case $v_i = 1$, note that $1 \cdot X_i^*(1) - T_i^*(1) = \sum_{v_{-i}} p_i(v_{-i})[x_i^*(1, v_{-i}) - t_{i1}^*(1, v_{-i}) - t_{i2}^*(1, v_{-i})] = 0 = 1 \cdot X_i^*(0) - T_i^*(0)$.

Finally, to show (8), first note that for γ^* we have $\mathcal{T}_1^* = \{I\}$ and $p(v|I) = p^*(v)$ so that we only need to show $\sum_{v \in V} \sum_{i=1}^n p^*(v)[t_{i2}^*(v) - cx_i^*(v)] \geq I$:

$$\sum_{v \in V} \sum_{i=1}^{n} p^*(v)[t_{i2}^*(v) - cx_i^*(v)] = \sum_{i=1}^{n} \sum_{v: x_i^*(v)=1} p^*(v)[1 - I/\bar{x}^*(v) - c] = \tag{40}$$

$$= \sum_{i=1}^{n} \sum_{v: x_i^*(v)=1} p^*(v)(1 - c) - I \geq 2I - I = I, \tag{41}$$

where the inequality follows since $x_i^*(1) = 1$ implies $v_i = 1$, and by the assumption $\sum_v \sum_i p^*(v) v_i (1 - c) \geq 2I$.

We next show that if condition (39) is violated so that

$$\sum_{v \in V} \sum_i p^*(v) v_i (1 - c) < 2I \tag{42}$$

there does not exist a transfer schedule t such that the direct mechanism $\gamma = (t, x^*)$ is feasible. In particular, we show there does not exist a transfer schedule t such that (t, x^*) satisfies (16)-(22).

For the efficient output schedule x^* it holds $V^1 = \{v | x_0^*(v) = 1\}$ and $V^0 = \{v | x_0^*(v) = 0\}$ so that $V = V^1 \cup V^0$.

For $v \in V^0$, it moreover holds $x_i(v) = 0$ so that conditions (19) and (20) taken together imply $\sum_i t_{i1}(v) + t_{i2}(v) \geq 0$. Multiplying by $p(v)$ and summing up over all v in V_0 yields

$$\sum_{v \in V^0} \sum_i p(v)[t_{i1}(v) + t_{i2}(v)] \geq 0 \tag{43}$$

For $v \in V^1$, condition (19) implies $\sum_i t_{i1}(v) = I$. Multiplying by $p(v)$ and summing up over all v in V_1 yields

$$\sum_{v \in V^1} \sum_i p(v) t_{i1}(v) = \sum_{v \in V^1} p(v) I = p^* I \tag{44}$$

Since $p^* \cdot p(v|I) = p(v)$ for $v \in V^1$, multiplying condition (17) by p^* yields

$$\sum_{v \in V^1} \sum_i p(v) t_{i2}(v) \geq p^* I + \sum_{v \in V^1} \sum_i p(v) c x_i^*(v) \tag{45}$$

Combining (44) and (45) yields

$$\sum_{v \in V^1} \sum_i p(v)[t_{i1}(v) + t_{i2}(v)] \geq 2p^* I + \sum_{v \in V^1} \sum_i p(v) c x_i^*(v) \tag{46}$$

Together with (43) this latter inequality implies

$$\sum_{v \in V} \sum_i p(v)[t_{i1}(v) + t_{i2}(v)] \geq 2p^* I + \sum_{v \in V} \sum_i p(v) c x_i^*(v) \tag{47}$$

Since $x_i^*(v) = v_i$ for $v \in V^1$ and $x_i^*(v) = 0$ for $v \in V^0$, multiplying (42) by p^* and rearranging terms yields

$$2p^* I + \sum_{v \in V} \sum_i p(v) c x_i^*(v) > \sum_{v \in V} \sum_i p(v) x_i^*(v). \tag{48}$$

Combining this latter inequality with inequality (47) yields

$$\sum_{v \in V} \sum_i p(v)[t_{i1}(v) + t_{i2}(v)] > \sum_{v \in V} \sum_i p(v) x_i^*(v). \tag{49}$$

Condition (16) implies after multiplying by $p_i(1)$ and summing over all i

$$\sum_i \sum_{v_{-i}} p(1, v_{-i})[t_{i1}(1, v_{-i}) + t_{i2}(1, v_{-i})] = \sum_i \sum_{v_{-i}} p(1, v_{-i}) x_i^*(1, v_{-i}) \tag{50}$$

Similarly condition (18) implies after multiplying by $p_i(0)$ and summing over all i

$$\sum_i \sum_{v_{-i}} p(0, v_{-i})[t_{i1}(0, v_{-i}) + t_{i2}(0, v_{-i})] = 0 = \sum_i \sum_{v_{-i}} p(0, v_{-i}) x_i^*(0, v_{-i}), \tag{51}$$

because $x_i^*(0, v_{-i}) = 0$.

Combining the latter two inequalities yields

$$\sum_i \sum_{v \in V} p(v)[t_{i1}(v) + t_{i2}(v)] = \sum_i \sum_{v \in V} p(v) x_i^*(v), \tag{52}$$

but this contradicts (49). Hence, under (42) there does not exist a combination (t, x^*) which satisfies (16)-(22) and, hence, x^* is not implementable. Q.E.D.

Proof of Proposition 3: To show the first statement, suppose for some consumer i we have $x_i^{sb}(1, v_{-i}) = 0 \neq v_i$. By (22), we have $x_i^{sb}(0, v_{-i}) = 0$ so that for consumer i

it must hold $v_i = 1$. But then by raising $x_i(1, v_{-i})$ to 1 and increasing $t_{i2}(1, v_{-i})$ by c, the objective is raised by $p(1, v_{-i})(1 - c) > 0$, while none of the constraints (16)-(22) are affected.

To show the second statement, suppose $x_0^{sb}(v) = 1$, while $x_0^*(v) = 0$. Then by setting it to 0 and setting $x_i^{sb}(v) = 0$, the changed direct mechanism satisfies all constraints (16)-(22) if the original one satisfied them. The change in $x_0^{sb}(v)$ raises the objective by I and the (possible) change in $x_i^{sb}(v)$ lowers the objective by at most $v_i(1-c)$. So the total raise in the objective it at least $I - \sum_i v_i(1-c)$. This is strictly positive, because $x_0^*(v) = 0$ implies $\sum_i v_i(1 - c) < I$.

To show the final statement, suppose $(\tilde{x}, \tilde{t})$ is such that it satisfies (16)-(22) while there is a $\hat{v}$ such that $\tilde{x}_0(\hat{v}) = 0$, while $\bar{v} = \sum v_i > 2I/(1 - c)$. We show that $(\tilde{x}, \tilde{t})$ is not a second best solution since there exists a $(\hat{x}, \hat{t})$ that also satisfies (16)-(17) but yields a strictly higher surplus.

To see this define $(\hat{x}, \hat{t})$ as follows. For all $v \neq \hat{v}$ set $\hat{x}_0(v) = \tilde{x}_0(v)$, $\hat{x}_i(v) = \tilde{x}_i(v)$, $\hat{t}_{i1}(v) = \tilde{t}_{i1}(v)$, and $\hat{t}_{i2}(v) = \tilde{t}_{i2}(v)$. Moreover, set $\hat{x}_i(\hat{v}) = \hat{v}_i$, $\hat{t}_{i1}(\hat{v}) = \hat{v}_i \cdot I/\bar{v} + \tilde{t}_{i1}(\hat{v})$, and $\hat{t}_{i2}(\hat{v}) = \hat{v}_i(1 - I/\bar{v}) + \tilde{t}_{i2}(\hat{v})$. Hence $(\hat{x}, \hat{t})$ differs from $(\tilde{x}, \tilde{t})$ only concerning $\hat{v}$.

Note first that $(\hat{x}, \hat{t})$ yields a higher surplus than $(\tilde{x}, \tilde{t})$, because the difference in surplus is

$$\hat{S} - \tilde{S} = p(\hat{v}) \left[\sum_i (\hat{v}_i - c)\hat{x}_i(\hat{v}) - I \right] = p(\hat{v}) \left[\sum_i (1 - c)\hat{v}_i - I \right] = p(\hat{v})[(1-c)\bar{v} - I] > 0.$$

It remains to be checked that $(\hat{x}, \hat{t})$ satisfies (16)-(22). That it satisfies (16), (18), (21) and (22) follows directly, because $(\tilde{x}, \tilde{t})$ satisfies these constraints and $(\hat{x}, \hat{t})$ is a transformation of $(\tilde{x}, \tilde{t})$ which preserves them.

Since (19) holds for $(\tilde{x}, \tilde{t})$, it clearly holds for $(\hat{x}, \hat{t})$ with respect to all $v \neq \hat{v}$. That (19) also holds with respect to $\hat{v}$, follows from

$$\sum_i t_{i1}(\hat{v}) = \sum_i \hat{v}_i \cdot I/\bar{v} + \tilde{t}_{i1}(\hat{v}) = \bar{v}I/\bar{v} + I\tilde{x}_0(\hat{v}) = I = I\hat{x}_0(\hat{v}).$$

Similarly (20), holds for all $v \neq \hat{v}$, while for $\hat{v}$ it follows

$$\sum_i t_{i2}(\hat{v}) = \sum_i \hat{v}_i(1 - I/\bar{v}) + \tilde{t}_{i2}(\hat{v}) \geq \sum_i \hat{x}_i(\hat{v})(1 - I/\bar{v}) > \sum_i \hat{x}_i(\hat{v})c,$$

where the first inequality uses that $(\tilde{x}, \tilde{t})$ satisfies (20) so that $\sum_i t_{i2}(\hat{v}) \geq 0$, as $\tilde{x}_i(\hat{v}) = 0$, and the second inequality follows from $\bar{v} > 2I/(1 - c)$, as this implies $c < 1 - I/\bar{v}$.

Finally, to see that $(\hat{x}, \hat{t})$ satisfies (17) because $(\tilde{x}, \tilde{t})$ does so, first define

$$\tilde{R}(v) = \sum_i [\tilde{t}_{i2}(v) - c\tilde{x}_i(v)] \text{ and } \hat{R}(v) = \sum_i [\hat{t}_{i2}(v) - c\hat{x}_i(v)].$$

It holds $\tilde{W}(v) = \hat{W}(v)$ for all $v \neq \hat{v}$, while for $\hat{v}$ it follows

$$\hat{R}(\hat{v}) = \sum_i [\hat{t}_{i2}(\hat{v}) - c\hat{x}_i(\hat{v})] = \sum_i (\hat{v}_i(1 - I/\bar{v}) + \tilde{t}_{i2}(\hat{v}) - c\hat{v}_i) \geq$$

$$\sum_i \hat{v}_i(1 - I/\bar{v} - c) = \bar{v}(1 - I/\bar{v} - c) = \bar{v}(1 - c) - I > I,$$

where the third equality uses that $(\tilde{x}, \tilde{t})$ satisfies (20) so that $\sum_i \tilde{t}_{i2}(\hat{v}) \geq \sum_i c\tilde{x}_i(\hat{v}) = 0$, and the final inequality uses $\bar{v} > 2I/(1 - c)$.

Since $(\tilde{x}, \tilde{t})$ satisfies (17) it follows from the definition of $p(v|I)$ that it is equivalent to

$$\sum_{v \in \tilde{V}^1} p(v)\tilde{R}(v) \geq I \cdot \sum_{v \in \tilde{V}^1} p(v).$$

so that with the former inequality it follows

$$\sum_{v \in \tilde{V}^1} p(v)\tilde{R}(v) + \hat{R}(\hat{v}) \geq I[\sum_{v \in \tilde{V}^1} p(v) + p(\hat{v})].$$

But since $\hat{V}^1 = \tilde{V}^1 \cup \{\hat{v}\}$, this is equivalent to

$$\sum_{v \in \hat{V}^1} p(v)\hat{R}(v) \geq I \cdot \sum_{v \in \hat{V}^1} p(v),$$

which is equivalent to saying that (17) holds with respect to $(\hat{x}, \hat{t})$. Q.E.D.

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