THE IMPACT OF ASYMMETRIC INFORMATION: APPLICATIONS IN ENTREPRENEURSHIP AND FINANCE

A Dissertation

by

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ABSTRACT

This dissertation consists of three essays examining the impact of information asymmetries in context of entrepreneurship and finance. Chapter 2, coauthored with Silvana Krasteva and Liad Wagman, focuses on the asymmetries between a firm and its (researcher) employee and studies the problem faced by a (researcher) employee when choosing whether to pursue an innovative idea as part of his employment at a firm or to form a start-up. An idea by its stand-alone value and by the degree of (positive or negative) externality that it may impose on the employing firm's existing profits if brought to market. The employee has private information about the innovation and his ability to independently develop it. Internal exploration, while allowing the employee to take advantage of any exploration support offered by the firm, reduces the employee's claim over his idea. We find that external exploration takes place for ideas weakly related to the firm's existing offerings, with other ideas being explored internally. We show that if the firm increases its support for exploration, it can induce the internal research of a wider range of ideas; however, by doing so, the firm also increases the likelihood of employees departing to pursue independent ventures at a later stage of development.

Chapter 3 analyzes the benefits of reducing information asymmetry in the credit markets. In their attempt to make more informed decisions, lenders often use a variety of information contained in a borrower's credit report. We find that if a borrower expects his future lenders to base their decisions not only on his repayment history but also on other factors like his income, length of history, etc., then his incentives to repay his present loan are weakened. In this case, he is more likely to strategically default on his loan especially for very high levels of interest rates. However, use of this extra information assists the lender in expeditious screening of the borrowers. Based on our results, we recommend that, in order to minimize defaults, more repayment history based products should be offered by the lenders. Evidence supporting the validity of this recommendation is provided in Chapter 4, coauthored with Vijetha Koppa. Using data from Prosper.com, we analyze the effect of reporting repayment histories to an additional credit bureau on borrowers' default rates and lenders' internal rates of return. A differences-in-differences comparison between high risk and low risk borrowers reveals that for high risk borrowers, the default rates were 9 to 11 percentage points greater and the internal rates of return were 13 percentage points lower in the pre-change period.

To my parents and grandparents.

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1. INTRODUCTION

The seminal works of Akerlof (1970) and Rothschild and Stiglitz (1976) highlighted some of the undesirable effects produced by information asymmetries in the markets and suggested that reducing information asymmetry results in a Pareto optimal outcome. This dissertation analyzes the impact of information asymmetry on employee start-ups; and benefits of reducing information asymmetry in consumer credit markets. This dissertation is organized as follows.

In Chapter 2, coauthored with Silvana Krasteva and Liad Wagman, we analyze the information asymmetries between a firm and its employees affect the firm's choice of employee benefits and employee's choice of nature of task to perform. We first study the problem faced by a research employee when choosing whether to pursue an innovative idea as part of his employment at a firm or to form a start-up. We characterize an idea by its stand-alone value and by the degree of (positive or negative) externality that it may impose on the employing firm's existing profits if brought to market. Internal exploration, while allowing the employee to take advantage of any exploration support offered by the firm, reduces the employee's claim over his idea. We find that external exploration takes place for ideas weakly related to the firm's existing product line, with other ideas being explored internally. Knowledge of employee's exploration strategy allows us to study the firm's decision to offer support for exploration. We show that if the firm increases its support for exploration, it can induce the internal research of a wider range of ideas; however, by doing so, it also increases the likelihood of employees departing to pursue independent ventures at a later stage of development. We further show that as the firm's bargaining position for capturing proceeds from innovations vis-à-vis employees strengthens, the firm's optimal level of support increases, and consequently its profits may decline. This happens because firm's stronger bargaining position makes internal exploration less attractive to the employee and he requires a higher level of support to remain with the firm.

Chapters 3 and 4 focus on information asymmetries in credit markets. Despite being highly competitive in nature, information asymmetries prevent the borrowers from benefiting from it. While some borrowers are denied loans (Stiglitz and Weiss, 1981), others experience high and sticky interest rates on their loans (Ausubel, 1991). In their attempts to make more informed decisions, lenders rely extensively on credit reports and scores provided by the credit bureaus. These credit scores are based on a range of information including borrowers' past mortgage payments, rent and other payments, existing credit mix, past bankruptcies, public records, recent credit inquiries, etc.. In Chapter 3, we analyze how using information beyond the borrowers' repayment history affects the credit market. The interaction between the borrowers and lenders is modeled as a dynamic game of incomplete information. We find that borrowers' optimal behavior is to repay their loans as long as their rating exceeds a threshold value. Further, this threshold increases if the future lenders are expected to use information beyond repayment history as it reduces the future costs of defaults. However, it hastens the discovery of the borrower's true type and results in more immediate screening. We recommend that, in order to minimize defaults, more repayment history based products should be offered by the lenders as they would reduce the moral hazard experienced by the borrower.

This recommendation made in Chapter 3 is tested in Chapter 4, coauthored with Vijetha Koppa, using data from Prosper Marketplace Inc. - an online peer-to-peer lending market. On August 16, 2007, their registered members were informed that while borrower's repayment activity in this market was already being reported to Experian, it would now also be reported to TransUnion. This policy change increased the penalties for defaults for borrowers. Using this policy change as a natural experiment, we analyze the impact of this change on future default rates. Comparing high risk borrowers with low risk borrowers reveals that, in the pre-change period, the default rates of high risk borrowers were 9 to 11 percentage points higher and internal rates of return were 13 percentage points lower. *Ceteris paribus*, this result is suggestive of the presence of moral hazard in this market and reinforces the recommendation made in Chapter 3 of offering more repayment history based products in the market.

2. THE 80/20 RULE: A FIRM'S CHOICE OF SUPPORT FOR THE EXPLORATION OF NEW IDEAS

2.1 Introduction

Evidence indicates that innovations developed by start-ups were often conceived by former employees of established firms, who undertook projects that had been overlooked by their employers (Bhide, 1994). These innovations are frequently closely related to the respective parent firms' lines of business. For instance, FriendFeed, Aardvark, and Nextstop were all start-ups founded by former Google employees and are closely connected to Internet search.[1]

While innovations may eventually be developed outside of the parent firm, the initial exploration often occurs within. In fact, many of the firms that bear a reputation for employees departing to form start-ups, also have in place generous policies for supporting the exploration of new ideas. Firms such as 3M and Google pioneered generous company policies for allowing employees to explore new ideas "on the company's dime." Google specifically states the following in the recruiting section of its website:[2]

> *"We offer our engineers '20-percent time' so that they're free to work on what they're really passionate about. Google Suggest, AdSense for Content, and Orkut are among the many products of this perk."*

A firm's choice to support and encourage exploration by its employees in lieu of negotiating exploration-contingent contracts can be understood in light of the

[1]Numerous other start-ups that bear a relationship to Google's product line were founded by former Google employees, including Ooyala, Dasient, TellApart, Cuil, Redbeacon, Mixer Labs, Howcast, MyLikes, Weatherbill, Doapp, reMail, Hawthorne Labs, and AppJet, among others.

[2]`http://www.google.com/intl/en/jobs/lifeatgoogle/englife/index.html`

nature of the innovation process. Innovative ideas are frequently the result of unpredictable and non-contractible initiatives, which go beyond employees' normally prescribed tasks (Hellmann and Thiele, 2011). Thus, incentive contracts based on measurable performance objectives studied in the literature (e.g., Holmström and Milgrom, 1991; Gibbons, 1998) are often hard to structure and evaluate in practice.

Google's 80/20 "Innovation Time Off" (ITO) policy, encouraging its engineers to take 20 percent of their time to work on company-related projects of their choosing, has led to some exceptionally successful products, including Gmail, AdSense, and Google News. 3M's analogous innovation model, which dates back to the 1950s,[3] has famously led to the development of the Masking Tape and Post-It Notes. This type of corporate innovation governance has been both formally and informally adopted in organizations ranging from high schools[4] to other technology firms.[5] Depending on a firm's specific policies, taking advantage of ITO may require obtaining a supervisor's approval, pursuing formal projects, and recording and regularly updating progress in a project-planning database. Hence, the degree to which information about an idea can be accessed by supervisors may vary across organizations.

While Google's ITO policy has attracted considerable media and practitioner attention in recent years, the literature has largely ignored the dynamics behind such corporate innovation policies. This paper aims to fill in this gap in the literature by offering an integrated model to (i) study a firm's choice of support for innovation, and (ii) examine the decision faced by employees of the firm in terms

[3] http://multimedia.3m.com/mws/mediawebserver?6666660Zjcf6lVs6EVs666IMhCOrrrrQ-

[4] http://www.centerdigitaled.com/training/Googles-8020-Principle-New-Jersey-School.html

[5] http://blogs.atlassian.com/2008/03/20_time_experiment/

of whether to pursue new ideas within the firm or as start-ups. In examining how an employee might respond to a firm's offer of exploration support, we are also able to uncover some of the forces behind start-up formation.

Since employees are encouraged to explore ideas that are related to their employers' lines of business, new ideas that are brought to market may interact with employers' existing products and profits. Accordingly, an integral component of our model is to allow for such profit interactions. On the employee's side, we characterize what types of ideas, in terms of their relationship to the employer's existing products, are more likely to be kept within the firm versus pursued as start-ups. In particular, we show how a firm's chosen level of support may interact with the likelihood and the timing of an employee's departure to form a start-up. On the firm's side, we study how its institutional framework and the level of market competitiveness interact with its choice of exploration support.

Consistent with the literature [e.g., Rogers (2003)], a new idea in our framework can be turned into a marketable innovation in two stages, exploration and development. A firm's support for exploration affects an employee's initial choice of whether to explore a new idea internally or externally as a start-up. From the employee's point of view, external exploration has the advantage of a higher appropriability of the innovation. The benefit of internal exploration is twofold. First, the employee can take advantage of any support offered by the firm. Second, internal exploration and handling of an idea may lead to a positive synergy surplus being shared between the firm and the employee.

As indicated above, a defining feature of our model is that ideas conceived by employees interact with their employers' existing lines of business, and thus have the potential to complement or compete with their employers' current offerings. Internal handling of an idea can enhance the value of complementary ideas and reduce the profit-eroding effects of substitute ideas, and thus is often efficient. However, negotiations between an innovating employee and the firm over the allocation of proceeds from a subsequent innovation are not always successful. Disagreements between the firm and an employee in our model take place due to the firm's limited information regarding the employee's entrepreneurial ability, which can result in an unsatisfactory allocation of proceeds. In turn, a downstream start-up formation may occur when an employee possesses both a high-valued idea and the requisite entrepreneurial ability to pursue a new venture.

Our model gives rise to the prediction that firms would tend to bleed out ideas that are weakly related to their current offerings, while ideas that are strongly related are handled internally — either developed inside the firm (for complements) or shelved (substitutes). Conditional on internal exploration, strongly complementary and substitute ideas tend to generate high bargaining surplus from internal handling. In turn, the firm is more willing to compensate an innovating employee for keeping these ideas within the firm. In contrast, the firm is less concerned about losing ideas that exhibit weak externalities — ideas which are also characterized by a low level of bargaining surplus.

From the perspective of an employee, it thus follows that the more likely an idea is to interact with the firm's existing line of business, the higher the employee's expected payoff from exploring the idea within the firm. When choosing to explore a new idea inside the firm, the employee weighs the cost of reduced appropriability and the potential benefit of sharing additional surplus from internal handling of an idea. Since this latter benefit is higher for ideas exhibiting stronger externalities, for a given level of support, the firm tends to induce the internal exploration of strong complements and substitutes, and bleeds out ideas that are weakly related to its line of business.

As the level of exploration support that is offered by a firm increases, more ideas are explored (at their initial stage) inside the firm. Interestingly, this also increases the likelihood of disagreements in the development stage, as it becomes increasingly difficult for the firm to distinguish between employees with low and high entrepreneurial abilities. This finding is consistent with the anecdotal evidence mentioned above, where firms which are most supportive of employee exploration, such as Google, are also renowned for their employees' leaving to form new ventures.

Having pinned down the effects of a firm's support for exploration on an employee's innovation strategy, we next examine the firm's initial choice of how much support to offer. In particular, we characterize how the firm's optimal level of support and expected profits are affected by changes in the firm's bargaining position and by changes in the competitive landscape. We show that the firm's optimal level of support rises as the firm is able to appropriate higher shares of the proceeds from newly developed ideas. This is because employees expect a less favorable outcome in the downstream, and are subsequently more likely to explore new ideas externally—unless the firm increases its level of support. We further show that the firm's profit may subsequently decrease because the cost of maintaining the flow of ideas can outweigh the gains in appropriating larger downstream proceeds.

2.1.1 Related literature

There is a significant body of literature that addresses different aspects of innovation in firms. A number of papers have analyzed the selection, management, and financing of innovation activities (e.g., Aghion and Tirole, 1994; Bernardo et al., 2008). The question of why established firms are unable to attract and retain profitable ideas has been on the forefront of the entrepreneurship literature in the last decade. Some explanations for start-up formation include information asymmetries and overly optimistic employees (Amador and Landier, 2003, Thompson and Chen, 2011); expropriation concerns due to either lack of commitment by the established firm or weak property rights (Anton and Yao, 1994; Anton and Yao, 1995; Wiggins, 1995); non-monetary benefits of exploration for the employee (Hellmann, 2007); know-how acquisition by employees increasing their entrepreneurship potential (Franco and Filson, 2006); inability of the established firm to prevent the development of profit-eroding innovations (Klepper and Sleeper, 2005); and limited capacity for internal ventures (Cassiman and Ueda, 2006). Our paper is closest to the literature that accounts for start-ups using informational asymmetries. The established firm in our model has both limited information about the value of conceived ideas by employees as well as the employees' entrepreneurial abilities, both of which impact employees' incentives for start-up formation.

While existing work has successfully accounted for an employee's decision to become an entrepreneur, there are still limited insights about the firm's incentives to support innovation. Our paper aims to shed light onto the underlying fundamentals that affect a firm's willingness to support exploration by employees, as well as the effects of increased exploration support on start-up formation. In this respect, our paper is related to Hellmann and Thiele (2011), who, similarly to our approach, develop a multi-tasking model. In their setting, a firm can influence an employee's incentives for exploration by appropriately designing his compensation structure. However, their model does not explicitly account for the possibility of an innovation interacting with the firm's existing line of products, which is a significant determinant of the firm's choice of exploration support in our framework.

The contribution of our paper is two-fold. First, since we view the choices of (i) exploration support by the firm, and (ii) start-up formation by employees, as inextricably interrelated, we present an integrated model that can successfully account for both phenomena. Second, in line with empirical evidence which shows that start-up activities are closely related to the parent firm (Klepper, 2009), we allow for the possibility of both complementary and substitute innovations. This allows us to study how innovation externalities affect both the level of exploration support as well as the likelihood of start-up formation.

The remainder of the paper is organized as follows. Section 2.2 formally sets up the model. Section 2.3 and 2.4 solve for expected payoffs from internal exploration and characterize the employee's optimal exploration strategy for a given level of exploration support by the firm. Section 2.5 addresses how the likelihood and timing of an employee's new venture formation is affected by the firm's choice of support and by the firm's prior beliefs that employees have high entrepreneurship abilities. Section 2.6 characterizes the optimal level of support and derives comparative statics on parameters that interact with the firm's choice of support. Section 2.7 concludes. All the proofs are relegated to Appendix A of this dissertation.

2.2 Model

Our model consists of a firm (f) and a research employee (e). The researcher receives a competitive wage, w, to work on the firm's core task. In the course of his work, the researcher may serendipitously come up with an innovative idea characterized by a stand-alone valuation, v_i, and an externality, Δ, that is imposed on the firm's profit. The stand-alone valuation is drawn from a Bernoulli distribution taking a high value $v_i = v$ with probability ψ and a low value $v_i = 0$ with probability $1 - \psi$. The externality imposed on the firm is drawn from a conditional distribution $F(\Delta | v_i)$ with support $[\underline{\Delta}, \overline{\Delta}]$, allowing for both positive (a complementary idea) or negative (a substitute idea) externalities.

Aware of the employee's innovation potential, the firm can choose to encourage internal exploration by providing the employee with exploration support, denoted by L. The firms' support includes benefits that affect both the employee's exploration success (productivity effect) as well as his satisfaction of being employed (retention effect). For example, the firm may offer free time on the company's dime, which can affect both the employee's ability to work on new ideas as well as his overall satisfaction with his job. The productivity effect, $p(L)$, captures the probability of successful exploration and satisfies $p'(L) > 0$ and $p''(L) < 0$. The retention effect, $u(L)$, captures the impact of the firm's support on the employee's happiness that is not related to his productivity. We normalize $u(0) = 0$ and assume that $u'(L) > 0$ and $u''(L) \leq 0$.

The firm's exploration support affects the employee's decision of how to handle his conceived ideas. The employee's choice and subsequent game is depicted by Figure 2.1. Upon coming up with an idea, the researcher faces three options: completely ignore the idea and focus on the core task (denoted by C), explore the idea externally via a start-up (denoted by E), and explore the idea internally (denoted by I). The first option of ignoring the idea and focusing on the core task results in a payoff of $w + u(L)$. The payoff from choosing the second option of external exploration via a start-up depends on the stand-alone value of the idea v_i, the expected probability of success outside the firm, given by p_0, and the researcher's privately observed entrepreneurial ability β, which determines his role

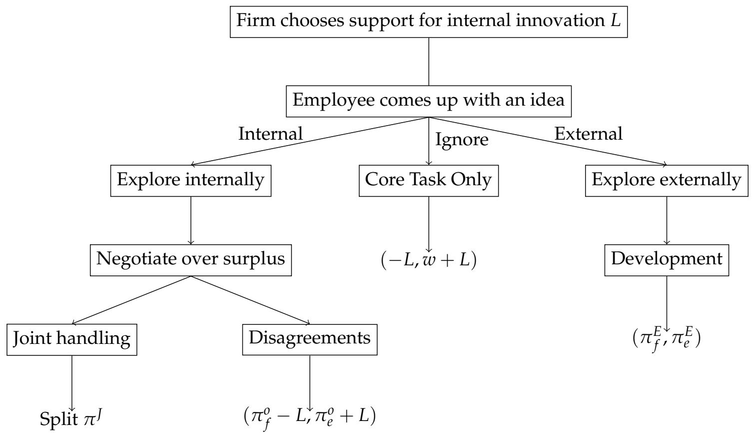


Figure 2.1: Timing of the game

and thus his payoff from a potential start-up.[6] The expected probability of success depends on the market conditions such as availability of venture capital and exploration support outside the firm. We assume that the firm and the employee have a common belief about the market conditions summarized by p_0. We allow for high and low entrepreneurial ability where $\beta \in \{\beta_L, \beta_H\}$ with $1 \geq \beta_H > \beta_L$ reflects the share of the start-up profit captured to the employee. The employee is privately informed about his entrepreneurship ability. The firm's prior belief that the employee is of high ability is denoted by $q \in (0, 1)$. Thus, the employee's expected payoff from external exploration is $\pi_e^E(v_i, \beta) = p_0 \beta v_i$ while the firm simply experiences the externality $\pi_f^E(v_i, \Delta) = p_0 \Delta \mathbf{1}(v_i = v)$.

The third option of internal exploration enables the employee to take advantage of the firm's exploration support L, but it also reveals the idea to the firm.

[6]For simplicity, we assume that the employee enjoys full appropriability of the idea when explored and developed independently. Extending the model to imperfect appropriability is straightforward and preserves the qualitative features of the model.

With probability $(1 - p(L))$ exploration fails to deliver a useful innovation resulting in a base wage payment of w for the employee and a status quo for the firm (which is normalized to 0). With probability $p(L)$, exploration is successful, giving rise to two possibilities. First, the employee and the firm can negotiate a mutually beneficial agreement for internal handling of the idea leading to a joint payoff of $\pi^J(v_i, \Delta) = \max\{g_\Delta \Delta + v_i, 0\}$, where $g_\Delta = g^s_\Delta < 1$ for substitutes and $g_\Delta = g^c_\Delta > 1$ for complements. This payoff reflects the fact that combing the expertise of the two parties allows for management of the externalities in a way that generates the most surplus. This entails tailoring the new product in a way that fits the existing firm's products better, i.e. $g^c_\Delta > 1$ and $g^s_\Delta < 1$, or shelving it whenever optimal. As a result, joint handling of the idea is always the efficient outcome.

The second possibility stemming from internal exploration is an independent development of the idea by the two parties. In this case, a share $\alpha_f v_i$ of the stand-alone value of the idea goes to the firm and $\alpha_e v_i$ goes to the start-up where $\alpha_f + \alpha_e \leq 1$ captures the profit-eroding effect of competition as well as the potential loss of surplus due to property rights dispute. As a result, the employee's payoff becomes $\pi^o_e(v_i, \beta, \alpha_e) = \beta\alpha_e v_i$, which is lower than his payoff from successful external exploration. The firm's payoff from independent development is $\pi^o_f(v_i, \Delta, \alpha_f) = (\alpha_f v_i + \Delta)\mathbf{1}(v_i = v) + \max\{0, \Delta\}(1 - \mathbf{1}(v_i = v))$, where $\mathbf{1}(\cdot)$ denotes the indicator function. These payoffs reflect the fact that the start-up develops only valuable ideas, while the firm may develop ideas with no stand-alone value if those ideas are complementary. We assume that for either type of employee external exploration and development of valuable ideas is more attractive than the core task (i.e., $\max\{p_0, \alpha_e\}\beta v \geq w$), which implies that the employee has a credible threat to develop these ideas without the firm. External exploration in our model is driven by the firm's inability to evaluate employee's ideas and entrepreneurship ability before ideas are explored.

The negotiation between the firm and the employee for internal handling of the idea is modeled as a random-proposer bargaining game with γ denoting the probability of the firm making a take-it-or-leave-it offer. The parameter γ can represent policies that the firm puts in place for negotiating proceeds from internally explored ideas.[7] From the perspective of employees, $1 - \gamma$ can represent an employee's ability to negotiate for a portion of the surplus from an internally-explored idea.

We solve for the Perfect-Bayesian equilibrium of this game by first analyzing the negotiation subgame following internal exploration, and then finding the expected payoffs for the firm and the employee from internal exploration. This allows us to determine the level of support that induces internal development of ideas with parameters (Δ, v_i). Then, by weighing in the costs and benefits of widening the spectrum of ideas that are brought in for internal exploration, we can characterize the firm's optimal level of support.

2.3 Internal Exploration: Negotiation Subgame

The negotiation subgame will determine what ideas are likely to be retained by the firm after initial internal exploration. In this stage, the firm and the employee bargain over the internal handling of the successfully explored idea. Recall that internal exploration reveals the idea to the firm. However, the employee is still privately informed about his entrepreneurship ability. Thus, disagreements may arise if the firm fails to compensate the high entrepreneurial employee sufficiently to prevent departure. Naturally, the firm's willingness to pay in order to retain

[7] We consider the possibility of γ being determined endogenously at the outset of the game in Section 6 and examine how the firm's and employee's payoff is affected by γ.

the employee depends both on the value of the idea as well as his belief regarding the employee's entrepreneurship ability. Note that this belief may be different from the prior q since the employee's choice of internal exploration may serve as a signal regarding his type. Let θ_I denote the firm's posterior belief that the employee is of high type (i.e., $\beta = \beta_H$), conditional on his idea being explored internally. The following Proposition characterizes the type of ideas that are likely to result in external development.

Proposition 1 *The firm and the researcher fail to reach an agreement with positive probability $\gamma\theta_I$ if and only if $v_i = v$, and $\Delta \in (\Delta_L(v,\theta_I), \Delta_H(v,\theta_I))$, where $\Delta_L(v,\theta_I)$ ($\Delta_H(v,\theta_I)$) is increasing (decreasing) in θ_I and $\Delta_L(v,\theta_I) = \Delta_H(v,\theta_I) = 0$ for $\theta_I \geq \frac{(\beta_H-\beta_L)\alpha_e}{1-\alpha_f-\beta_L\alpha_e} \in (0,1)$.*

Proposition 1 states that the firm may fail to reach an agreement with high-ability employees when their ideas have high stand-alone values and are only weakly related to the firm's existing line of business. To glean some insight into this result, let us consider the case of complementary ideas. A weakly complementary idea adds little to the firm's existing profit. Thus, the firm makes a low compensation offer of $\beta_L\alpha_e v$ to the researcher, which is subsequently rejected if the researcher has a high entrepreneurial ability. As the complementarity of the idea strengthens, the firm has more to lose from failing to reach an agreement and increases its offer to $\beta_H\alpha_e v$, which in turn is accepted by both types. Further, the disagreement region $[0, \Delta_H(v,\theta_I)]$ shrinks as the firm's belief of facing a high type increases, since the firm's expected payoff from making a low compensation offer decreases. This induces the firm to increase its offer for a wider range of complementary ideas, effectively reducing disagreements.

The intuition for substitute ideas is similar. In this case, the firm is concerned about losing ideas that would result in substantial profit erosion if developed externally. Thus, the firm is willing to make a high compensation offer whenever faced with an idea that exhibits a large negative externality. As the likelihood of facing a high-ability employee increases, the firm in turn increases its offer on a wider range of substitute ideas. Proposition 1 also notes that there exists a cut-off value for the firm's posterior belief θ_I, given by $\frac{(\beta_H - \beta_L)\alpha_e}{1-\alpha_f-\beta_L\alpha_e} < 1$, such that no ideas are lost in the downstream for beliefs at or above this cutoff.

Armed with the equilibrium characterization of the negotiation stage, we can calculate the firm's and the employee's expected payoffs, which are important determinants of the incentives for internal exploration by the employee and the firm's exploration support in the earlier stages of the game. The following Corollary describes how these payoffs are affected by the degree of externality, Δ.

Corollary 1 *Let $\pi_f^N(v_i, \Delta, \theta_I)$ and $\pi_e^N(v_i, \Delta, \beta, \theta_I)$ denote the firm's and the employee's expected payoff from the negotiation stage.*

1. *If $\Delta > 0$, then $\pi_f^N(v_i, \Delta, \theta_I)$ is strictly increasing and $\pi_e^N(v_i, \Delta, \beta, \theta_I)$ is (weakly) increasing in Δ.*

2. *If $\Delta < 0$, then*

   a) *$\pi_f^N(0, \Delta, \theta_I)$ and $\pi_e^N(0, \Delta, \beta, \theta_I)$ are independent of Δ.*

   b) *$\pi_f^N(v, \Delta, \theta_I)$ is strictly increasing in Δ while $\pi_e^N(v, \Delta, \beta, \theta_I)$ is strictly decreasing in Δ.*

It follows from Corollary 1 that independent of the value of an idea, the employee and the firm both benefit from strong complementarity. This is a direct consequence of the value-enhancing property of internal development of complementary ideas (i.e., $g^c_\Delta > 1$). As the magnitude of the externality rises, the bargaining surplus $\pi^J - \pi^o_f - \pi^o_e$ and the firm's outside option π^o_f increase, leading both the firm's and the employee's internal payoffs to increase as well.

For substitute ideas, the employee benefits from a credible threat of imposing a stronger negative externality to the firm since it increases the firm's eagerness to retain the idea in-house. If the idea has a low stand-alone value, the employee is unable to credibly commit to develop the idea and thus the bargaining surplus is 0. In contrast, for high-value ideas, $v_i = v$, external development is feasible and the bargaining surplus is decreasing in Δ since a weaker substitute idea constitutes less of a threat to the firm's existing profit. As a result, the firm's expected payoff is increasing in Δ and the employee's expected payoff is decreasing in Δ.

Overall, corollary 1 reveals that the employee benefits more from ideas that impose stronger externalities on the firm. This, in turn, implies that the employee requires weaker incentives to bring such ideas in-house. We next study the optimal exploration strategy by the researcher.

2.4 Optimal Exploration Strategy

In this stage, the employee with an innovative idea observes the level of support offered by the firm and chooses either to ignore the idea (C), explore internally (I) or pursue the idea outside the firm (E). The payoff from ignoring the idea is given by $\pi^C_e(L) = w + u(L)$. His payoff from exploring the idea internally is $\pi^I_e(v_i, \Delta, \beta, \theta_I, L) = p(L)\pi^N_e + (1 - p(L))w + u(L)$ and external exploration results in $\pi^E_e(v_i, \beta) = p_0\beta v_i$. The employee chooses the exploration strategy that leads to the highest possible payoff. We assume that whenever indifferent, the researcher breaks the indifference in favor of ignoring the idea over exploring as well as exploring internally over externally.[8]

Low valued ideas are never explored outside the firm and thus the employee chooses either to ignore them or explore them internally. Moreover, we know from the negotiation's stage that the employee benefits from exploring low valued ideas only if they add substantial value to the firm. Therefore, the employee will explore only ideas that are sufficiently complementary and ignore the rest.

In contrast, high valued ideas are always profitable to explore either internally or externally. From Corollary 1, we know that the employee's downstream payoff is increasing in the degree of externality that the idea is imposing on the firm. As a result, strongly complementary or substitute ideas will require lower powered incentives in order to induce internal exploration. Moreover, the low entrepreneurship type has lower outside option for any realization of Δ and thus should be more willing to bring an idea inside the firm. The following Proposition formalizes this intuition.

Proposition 2 *For a given L, if* $v_i = 0$*, both employee types choose to ignore the idea if* $\Delta \leq \frac{w}{g^c_\Delta - 1} = \Delta^*_c(L, 0, \beta)$ *and explore internally otherwise. If* $v_i = v$*, there exist cutoffs* $\Delta^*_s(L, v, \beta_H) \leq \Delta^*_s(L, v, \beta_L) \leq 0$ *that are increasing in L and* $0 \leq \Delta^*_c(L, v, \beta_L) \leq \Delta^*_c(L, v, \beta_H)$ *that are decreasing in L, such that:*

a) If $\Delta \notin (\Delta^*_s(L, v, \beta_H), \Delta^*_c(L, v, \beta_H))$*, both types explore internally and* $\theta^*_I = q$*.*

b) If $\Delta \in (\Delta^*_s(L, v, \beta_H), \Delta^*_s(L, v, \beta_L))$ *or* $\Delta \in (\Delta^*_c(L, v, \beta_L), \Delta^*_c(L, v, \beta_H))$ *a high-type employee explores externally, a low-type explores internally, and* $\theta^*_I = 0$*.*

c) If $\Delta \in (\Delta^*_s(L, v, \beta_L), \Delta^*_c(L, v, \beta_L))$*, both types explore externally and* $\theta^*_I = 0$*.*

[8] Such tie breaking rule is in favor of efficiency whenever exploration is costly. For simplicity, we abstract from a costly exploration effort since it results in similar qualitative results as the ones presented here.

Proposition 2 confirms that ideas with a low outside option are explored internally only if they sufficiently complement the firm's existing products since these are the ideas that generate sufficient bargaining surplus to justify their exploration. In contrast, if the conceived idea has a high outside option, both strong complements and substitutes are explored in-house. This is because the employee has a credible threat of external development, allowing him to benefit from exploring ideas that impose a high negative externality to the firm.

Proposition 2 states that strongly complementary or substitute ideas are explored internally by both types, preventing the buyer from updating her prior regarding the employee's entrepreneurship type. Since the low type of employee is more eager to explore in-house, ideas with intermediate levels of externality are explored internally only by the low type of employee, causing him to perfectly reveal his type to the firm. Finally, ideas that are weakly related to the firm's line of business are explored externally by both types. The off-equilibrium belief by the buyer that the employee has a low entrepreneurship ability in this case prevents the low type from deviating and exploring internally.

Combining the findings from Propositions 1 and 2, if follows that researchers who leave their employment to form start-ups do so to pursue high-value ideas that are weakly related to the firm's line of business. Moreover, a researcher may choose to exit the firm either at the initial exploration stage or at the downstream development stage. The next section examines how the level of support by the firm affect both the likelihood and the timing of a researcher's potential departure to form a start-up.

2.5 Timing of the Researcher's Departure

The level of support offered by the firm helps determine whether the employee pursues internal exploration. It is intuitive that a higher level of support results in increased exploration activity within the firm. Proposition 1 points out, however, that the firm will not always be able to retain the ideas that are explored in-house if it is unable to screen out the employee's entrepreneurial ability and offer a sufficient amount of compensation. As the following proposition reveals, while increasing support induces further in-house exploration, doing so may also result in a higher rate of disagreements in the downstream, as it becomes increasingly difficult for the firm to distinguish between high- and low-ability employees.

Proposition 3 *The likelihood of internal exploration is (weakly) increasing in L. For $q \geq \frac{(\beta_H - \beta_L)\alpha_e}{1-\alpha_f-\beta_L\alpha_e}$, no downstream disagreements occur. For $q < \frac{(\beta_H - \beta_L)\alpha_e}{1-\alpha_f-\beta_L\alpha_e}$, there exists $\tilde{L}$ such that for $L > \tilde{L}$ the likelihood of downstream disagreements is increasing in L.*

An increase in L makes internal exploration more attractive for both employee types. Thus, $\Delta_s^*(L, v, \beta)$ is increasing in L and $\Delta_c^*(L, v, \beta)$ is decreasing in L, effectively reducing the range of ideas explored outside the firm. The likelihood of downstream disagreement depends on the firm's ability to distinguish the employee's entrepreneurial ability. Proposition 3 states that if a high type is sufficiently likely (i.e., $q \geq \frac{(\beta_H - \beta_L)\alpha_e}{1-\alpha_f-\beta_L\alpha_e}$), then this is not an issue, since the firm always finds it optimal to make a generous offer in the downstream that is acceptable to both employee types. For $q < \frac{(\beta_H - \beta_L)\alpha_e}{1-\alpha_f-\beta_L\alpha_e}$, however, the firm may choose to make a low price offer if the idea is weakly related to the firm's existing products and it is sufficiently likely that the employee is of low entrepreneurship ability. This will not cause disagreements for low levels of support since the firm will lose the high entrepreneurship employee in the exploration stage, allowing it to perfectly screen out the employee's type for a wide range of weakly related ideas $\Delta \in (\Delta_s^*(L, v, \beta_H), \Delta_c^*(L, v, \beta_H))$. As L increases, however, exploration becomes more attractive for the high entrepreneurship employee. As a result, the firm may fail to reach an agreement for moderate complements or substitutes, i.e., for $\Delta \in (\Delta_L^*(v, q), \Delta_s^*(L, v, \beta_H))$ or $\Delta \in (\Delta_c^*(L, v, \beta_H), \Delta_H^*(v, q))$. This occurs because the low likelihood of a high type and the moderate externality make it optimal for the firm to make a low offer in the downstream negotiation. As L increases, the region of downstream disagreements expands, as the high-type's choice of exploring more ideas in-house makes it harder for the firm to distinguish between the two types.

From the above, it follows that the firm may never be able to implement an exploration-support strategy that eliminates inefficient departures by employees. Interestingly, all else being equal, our findings predict that firms with higher level of exploration support are also the ones that will experience more disagreements and loss of ideas initially explored in-house. This is consistent with anecdotal evidence from highly innovative firms, such as Google, that are known for their generous exploration support policies, as well as for their high rates of employee departures to pursue new ventures.

2.6 Optimal Support for Exploration

Having identified the characteristics and timing of the departure of ideas, we focus on the firm's choice of exploration support. At the time of setting its support, the firm has limited information about the characteristics of the ideas that are likely to emerge. Hence, its decision is based only on its prior belief about the value of the conceived ideas as well as the entrepreneurship ability of the employee.

The firm's exploration support affects both the employee's willingness to pursue internal exploration as well as the likelihood of successful exploration. The firm's expected payoff from internal exploration of an idea characterized by (Δ, v_i, β) is $\pi_f^I(v_i, \Delta, \beta, L) = p(L)\pi_f^N(v_i, \Delta, \theta_I^*)$ while its payoff from external exploration is given by $\pi_f^E(v_i, \Delta)$. Thus, the firm's surplus of inducing internal exploration of an idea with characteristics (v_i, Δ, β) is $S_f\left(v_i, \Delta, \beta, L\right) = \pi_f^I(v_i, \Delta, \beta, L) - \pi_f^E(v_i, \Delta)$. By Proposition 2, for high valued ideas, this surplus is realized only if the idea is close enough to the existing firm's products (i.e., $\Delta \notin \left(\Delta_s^*\left(L, v, \beta\right), \Delta_c^*\left(L, v, \beta\right)\right)$). If the idea has a low stand-alone value, internal exploration takes place for ideas with strong positive externality. Letting $\Delta_s\left(L, 0, \beta\right) = \underline{\Delta}$, this implies that internal exploration of low value ideas occurs for $\Delta \notin \left(\Delta_s^*\left(L, 0, \beta\right), \Delta_c^*\left(L, 0, \beta\right)\right)$. Then, in the first period, the firm choice of exploration support is represented by the following optimization problem.

$$\max_L \; E\left[S_f\left(v_i, \Delta, \beta, L\right) | \Delta \notin \left(\Delta_s^*, \Delta_c^*\right), v_i, \beta\right] - \tag{2.1}$$

$$L\big(1 - \Pr\left(v\right)\left(F\left(\Delta_c^*|v\right) - F\left(\Delta_s^*|v\right)\right)\big)$$

Equation 2.1 simply states that the firm maximizes its expected surplus from internal exploration minus the expected expenditure on exploration support. Note that the firm incurs L only if the employee chooses to stay within the firm either to explore an innovative idea of work on the core task. The first order condition characterizing the optimal level of support is given by:

$$E\left[\frac{\partial S_f\left(v_i, \Delta, \beta, L\right)}{\partial L} | \Delta \notin \left(\Delta_s^*, \Delta_c^*\right), v_i, \beta\right] + \tag{2.2}$$

$$E[S_f(v_i,\Delta_s^*,\beta,L)\,f(\Delta_s^*|v_i)\,\frac{d\Delta_s^*}{dL},v_i,\beta] - E[S_f(v_i,\Delta_c^*,\beta,L)\,f(\Delta_c^*|v_i)\,\frac{d\Delta_c^*}{dL},v_i,\beta]$$

$$= 1 - \Pr(v)\left[F(\Delta_c^*|v) - F(\Delta_s^*|v)\right] + L\Pr(v)\left[f(\Delta_c^*|v)\,\frac{d\Delta_c^*}{dL} - f(\Delta_s^*|v)\,\frac{d\Delta_s^*}{dL}\right]$$

At the optimum, the firm equates the marginal benefit and cost of exploration support. The marginal benefit of internal exploration includes an increase in the likelihood of success from internal exploration, captured by the first term in equation (2.2), and the increase in the employee's willingness to pursue ideas internally, captured by the second term in equation (2.2). The marginal cost of internal exploration includes the cost of increasing support for employees that are already successfully retained and the additional cost associated with the higher retention likelihood.

The optimality condition given by equation (2.2) allows us to study how the optimal level of support and the profitability of internal exploration is affected by the fundamentals of our model. The next section discusses the effect of the firm and the employee's bargaining power, captured by γ, and the market and legal environment, captured by α_e and α_f, on the firm's support for exploration.

2.6.1 Changes in optimal level of support

The firm's bargaining position in the downstream negotiation with the employee depends on various factors such as the firm's control over the development process, the importance of the employee's expertise in the successful development of the product, and the institutional and legal framework within which negotiations take place. Some of these factors are within the firm's control, as they are impacted by the firm's organizational structure. For instance, a more hierarchical organizational structure tend to tilt the bargaining power in favor of the firm, while a flatter structure gives more autonomy to employees. The following

Proposition states that a higher bargaining power by the firm is associated with a greater support for exploration.

Proposition 4 *The firm's optimal level of exploration support $L^*(\gamma)$ is increasing in γ.*

The increase in the firm's bargaining power has a two-fold effect. First, it increases the firm's surplus from internal exploration, which makes the firm more eager to support the pursuit of new ideas by the employees. Second, it makes the employees less willing to remain within the firm whenever they conceive a valuable idea. This causes the firm to increase its support further in order to ensure internal exploration.

While increasing the firm's bargaining power in the downstream clearly makes the firm more eager to support exploration, such change may sometimes adversely affect the firm's profitability. A *ceteris-paribus* increase in the firm's bargaining power, γ, has a positive effect on the firm's profitability. However, γ also affects the employee's willingness to pursue internal exploration. As a result, the firm not only loses the surplus generated by the marginal ideas, but also incurs a higher cost on the ideas that remain inside the firm. As the following example illustrates, the negative strategic effect on firm's profits through fewer ideas being explored internally could dominate the direct positive effect of the higher bargaining power.

Example 2 *The stand-alone value of the idea is $v_i = 500$ with probability 0.8 and $v_i = 0$ otherwise. The productivity effect is captured by $p(L) = \left(1 - e^{-.5L-0.1}\right)$ with external success probability $p_o = 1 - e^{-0.1}$. The retention effect is captured by $u(L) = 0.3L^{0.9}$. The externality parameter is a draw from a uniform distribution $U \sim [0, 1500]$ with probability $\lambda_{v_i} = \begin{cases} 0.9 & if \quad v_i = 0 \\ 0.1 & if \quad v_i = 500 \end{cases}$ and a draw from a uniform $U \sim [-1500, 0]$*

with probability $1 - \lambda_{v_i}$. *Internal exploration results in* $g_\Delta^c = 1.1$, $g_\Delta^s = 0.9$ *and a competition effect* $\alpha_e = 0.05$ *and* $\alpha_f = 0.9$. *The prior belief of the employee being of high entrepreneurship ability is* $q = 0.4$ *with* $\beta_L = 0.1$ *and* $\beta_H = 0.9$. *The employee's wage rate from the core task is* $w = 0.2$.

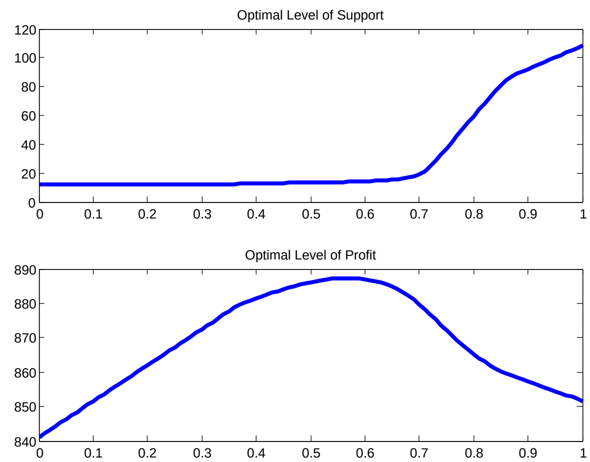


Figure 2.2: The effect of strengthening the firm's bargaining position.

As can be seen from Figure 2.2, an increase in γ *causes the firm to increase their support in order to increase the likelihood of successful exploration and counter the negative impact of* γ *on the employee's incentives to explore internally. The firm's profit is initially increasing in* γ, *reaches the maximum around* $\gamma = 0.6$ *and then starts to decrease as the negative strategic effect overwhelms the positive direct effect.*

The firm's willingness to support internal exploration is also affected by the market conditions and the legal allocation of property rights, which are captured by the parameters α_e and α_f in our model.

Proposition 5 *The firm's optimal level of exploration support* L^* *is increasing in* α_f, *and* *decreasing in α_e.*

This suggests that a firm could benefit from taking steps to diminish its downstream bargaining position by, for instance, choosing an organizational structure that assigns greater control of new ideas to research employees. This is in line with studies in psychology which show that firms can enhance profits by endowing employees with increased autonomy in their work.

2.7 Conclusions

Our analysis reveals that researchers who leave their employment to form start-ups tend to develop products that are weakly related to their employer's line of business. While increasing the level of support for exploration may be a powerful tool to encourage internal exploration by research employees, we find that such policies may also increase employee departure at later stages of development. This finding is consistent with anecdotal evidence suggesting that the firms with the most generous exploration policies are also the ones that experience a significant number of departures by employees to form new ventures.

When choosing its optimal level of support, the firm balances the benefits of inducing higher levels of exploration in-house with the cost of providing support. We find that the firm's support is higher as its bargaining position strengthens vis-a-vis the employee when negotiating for the development of the new product. The level of support is also likely to be higher if the anticipated ideas are likely to be more weakly related to the existing firm's like of business.

Future work can take on a number of directions. One fruitful direction for future work includes a mechanism-design framework, where the firm is able to structure roles for employees in order to make the discovery of certain innovations more likely (e.g., innovations that are more complementary to the firm's existing line of products). Another interesting question to consider is the firm's incentives to commit to a development strategy ex-ante in order to impact the employee's exploration choice.

3. IS MORE INFORMATION ALWAYS BETTER? A CASE IN THE CREDIT MARKETS

3.1 Introduction

Information asymmetries in the market provides incentives to the informed players to behave opportunistically and can result in undesirable outcomes in one-shot interactions (Akerlof (1970), Rothschild and Stiglitz (1976)). However, repeated interactions can alter their incentives and encourage them to behave differently (Kreps and Wilson (1982),Milgrom and Roberts (1982)). These repeated interactions either take the form of one long-lived player sequentially interacting with a series of short-lived players or two long-lived players repeatedly interacting with each other. In order for them to alter the informed player's behavior, it is imperative that before each interaction, short-lived players (or uninformed long-lived player) are familiar with the long lived player's past behavior and base their current action on that information. This requires that all the uninformed players have unbounded memory and can freely communicate with each other. While prevalence of computers makes it easier to satisfy the first condition, the second one is much harder to appease.

Consider the example of consumer credit markets. A typical borrower in today's market owns a credit card from Bank A, a personal loan from Bank B, a mortgage loan from Bank C, and so on. In this market, allowing the short-lived players to communicate freely would imply that all the banks directly share their private information about the repayment behavior of this borrower. However, in US credit markets, a credit bureau like Experian, Equifax or TransUnion facilitates the transfer of information among all the banks. Banks report the borrower's repayment behavior on their respective loans to the credit bureau, which in turn, dissipates this information to future banks in the form of a credit report. The credit report of a borrower contains a wider range of arguably related information like past bankruptcies, public records, length of credit history, recent credit inquiries, etc.. In addition to containing most of this information directly, the credit report also contains a summary statistic (commonly known as credit score).[1] This credit score is a predictor of the repayment probabilities of loans and is a significant determinant of the offered terms and conditions on the loans. The *"credit score is determined by a complex formula that takes into account over 100 different factors"*[2]. As a result, in making their lending decisions, future lenders utilize information beyond borrower's repayment histories. Motivated by this observation, this paper analyzes the impact of this extra information on the behavior of the players in the credit market.

We model the credit market interactions as a dynamic game of incomplete information between a single borrower and a sequence of lenders. The borrower repeatedly invests the borrowed money in risky projects and has private information about the success probabilities. The outcome of the project is also privately observed by him and affects his ability to repay his loan. The market suffers from both adverse selection (due to *ex-ante* private information) and moral hazard (due to *ex-post* non verifiability of the project outcome). In order to assist the uninformed lender in his decision, he is offered access to a rating which is indicative of the repayment likelihood. This rating is issued by a third party who has private access to the borrower's repayment history and can imperfectly observe a sig-

[1]See `http://www.experian.com/credit_report_basics/pdf/samplecreditreport.pdf` for a sample credit report and `http://www.experian.com/consumer-products/credit-score.html?intcmp=smplpdf` for details on credit scores

[2]`http://epic.org/privacy/creditscoring/#Score\%20Calculation`

nal informative of other related characteristics. Direct communication among the lenders in different stages of the game is assumed to be prohibitively costly. Thus, by maintaining a record of repayment behavior and providing it to the lenders in the current stage (in the form of a rating), the rating agent facilitates the flow of information among the lenders in different stages of game.

This paper deviates from a majority of repeated games literature by relaxing the assumption of the presence of commitment (or behavioral) types of players. An implication of doing so is the potential existence of an equilibrium in which repaying today's loans may not always result in higher continuation payoffs in future. Or in other words, the costly choice of repaying today would not provide any benefits (it can potentially hurt) in future. As a result, using repayment history for making future lending decisions encourages even more defaults in current period and defeats the purpose of using history to form future expectations.

The borrower types in our model differ from each other in terms of the probabilities with which their projects fail and they are forced to default on their loans. We find that, if the project does not fail, borrowers of all types follow a threshold strategy in equilibrium: default for lower ratings and repay for higher ratings. Consistent with the existing literature, we find that using behavioral history to predict the likelihood of future repayments is beneficial as it encourages the borrowers to repay their loans more often.

This paper is closely related to an emerging literature which allows the possibility of a third party facilitating the exchange of information among short lived players (e.g., Liu and Skrzypacz (2011), Doraszelski and Escobar (2012) and Ekmekci (2011)). Similar to these papers, we allow for the presence of another non-strategic long run player who can observe the complete history of the game. He alters and restricts the short run players' access to history by either wiping the history after a fixed period of time (Liu (2011)), making it costly for the short run players to access the long run player's history in which case he might himself choose to access only limited history, (Liu and Skrzypacz (2011)) or providing a discrete rating for each long run player from the set of finitely possible ratings (Doraszelski and Escobar (2012) and Ekmekci (2011)). In our model, in addition to observing game history, the non-strategic long run player can observe a signal related to the hidden characteristics of the informed player. He then processes this information and provides it to the short run player in the form of a continuous rating. Consequently, the lender's expectations about borrower's future behavior are now based on information other than repayment history too. We find that utilizing information this extra information has a negative impact on the repayment behavior of the borrowers as it reduces the effect of their current choice on their continuation payoffs. These greater defaults translate to higher interest rates for some ratings and no lending for others. As a result, the impact of this practice on the borrower's welfare is not clear.

Similar to Cripps et al. (2004) and Cripps et al. (2007), we find that lenders eventually learn about the borrowers's true type. The extra information fastens their learning and allows them to weed out the undesirable types of borrowers sooner than before.

Anecdotal evidence indicates that banks place a great deal of importance on the credit score while scrutinizing loan applications and outrightly rejects applications with a not-so-good credit score. In light of our results, we recommend that in order to maximize repayment incentives, more products based on borrower's repayment history should be offered in the market.

The rest of this paper is organized as follows. Section 3.2 describes the model and the equilibrium is characterized in Section 3.3. Section 3.4 analyzes the impact of information on the borrower behavior, lender behavior and his beliefs. Section 3.5 exemplifies the existence of an equilibrium where using repayment history encourages greater defaults. Section 3.6 discusses the wider applicability of our results. Section 3.7 concludes. All the proofs are relegated to Appendix B .

3.2 Model

3.2.1 Description

Consider a finite horizon discrete time economy consisting of three types of risk neutral players - a borrower, a lender and a rating agency. Over time, a given (long lived) borrower interacts with a sequence of (short lived) lenders. The short life of the lenders captures two main features of US credit market – first, the ability of the lenders to change the terms and conditions of an existing loan at any time and charge higher default interest rate; and second, the prevalent competition in the credit market where borrowers can conveniently switch among the lenders.

At the beginning of each period t, the borrower is endowed with a project which requires an investment of \$1 and yields a stochastic output, denoted by Y_b. He has no monetary endowment. The output from the project can not be transferred intertemporally and he is dependent on external sources of funding in each period. A funded project yields a privately observed payoff of $Y_b \in \{M, 0\}$ to the borrower. If $Y_b = M$, the project is a success. (Otherwise, it is a failure.) The action space of the borrower is contingent on Y_b. If $Y_b = M$, his action space is given by set $\left\{d, \overline{d}\right\}$, where d denotes *default* and $\overline{d}$ denotes *repayment* on the loan. Upon success, the borrower strategically chooses between default and repayment. Otherwise, if $Y_b = 0$, his action space is singleton set $\{d\}$, where d denotes *default* on loan and he defaults non-strategically. The probability with which the project yields $Y_b = M$ is privately known type of the borrower and is denoted by $\theta_j \in$

$\{\theta_H, \theta_L\}$, where H stands for high and L stands for low. The prior belief that $\theta_j = \theta_H$ is $q \in (0, 1)$. The type of the borrower remains unchanged throughout the game. Without loss of generality, we assume $\theta_H > \theta_L$.

In each period, a continuum of identical lenders operate in a perfectly competitive market.[3] At the beginning of each period t, each lender is endowed with \$1 and has the option of either investing it in risk-free government bonds for a sure return of $\$1 + i^{rf}$, $i^{rf} \geq 0$, or lending it to a borrower. Conditional on lending, if the borrower chooses *repayment* ($\bar{d}$), the lender receives the principal and the pre-agreed interest rate and his payoff is given by $Y_l = 1 + i^t$. In contrast, upon observing a *default* (d), *ex-ante* a lender cannot distinguish a strategic *default* from a non-strategic one. However, he can costlessly and privately make use of a punishment mechanism which can observe the true outcome of the project with probability β and transfer borrower's payoff Y_b to him, before the borrower can consume it, resulting in an expected payoff of $Y_l = \beta Y_b$ to him. β captures the legal remedies available to the lenders if borrowers default on their loan. The borrower is protected by limited liability and all the investment risk is borne by the lender.

We make the following assumptions about the parameters of the model:

Assumption 1: $\theta_H \beta M > 1 + i^{rf} > \theta_L M$.

The lender's expected payoff from lending to a high type of borrower who defaults surely exceeds the expected payoff from lending to a low type of borrower who repays surely. If there is complete information about borrower's type, then lenders always find it optimal to lend to the high type of borrower and never to the low type of borrower. An immediate implication of this assumption is that

[3] Equivalently, there can be two Bertrand competitive lenders.

$\beta > \frac{1+i^{rf}}{\theta_H M} > 0$. That is, the borrowers experience non-negligible threat of punishment in each stage.

Assumption 2: $\theta_L M \geq 1$.

Investing money in the projects is an optimal choice for all the borrowers. This assumption is necessary to ensure that reputation concerns continue to discipline θ_H borrower for a longer time.[4]

The rating agent is a non-strategic player and has four defining features reflective of the credit bureaus in US. First, he can observe the borrower's default history, but can not identify the underlying cause – a very high interest rate, project failure or borrower's strategic choice. Second, he can observe an imperfectly informative private signal $s^t \in \{s_H, s_L\}$ correlated with the private information θ of the borrower. If $\theta = \theta_H$ (resp. θ_L), then a signal $s^t = s_H$ (resp. s_L) is observed with probability $p_s \in \left(\frac{1}{2}, 1\right)$[5]. Higher values of p_s correspond to more informative signals. Third, he facilitates the flow of this information among lenders in different stages. Lastly, he processes all the available information and issues a rating $R_t \in [0,1]$ in each period which is interpreted as the likelihood that the borrower is of type θ_H and is reflective of lenders' beliefs about the borrower's type.

[4]If $\theta_L M < 1 < \theta_H M$, then only the high type of borrower finds it optimal to invest. Hence, the lender expects to receive a positive return only if $\theta = \theta_H$ and interest rate equation is given by: $1 + i^t = \beta M + \frac{\left(1+i^{rf}\right) - R_t \theta_H \beta M}{R_t \theta_H r_H^t}$. If $\theta_H M < 1$, then neither type of borrowers would find it optimal to invest the borrowed money.

[5]If $p_s = \frac{1}{2}$, then signals are completely uninformative of the true state and will not increase the information available to the rating agent. This would correspond to the situation when no signals are observed. If $p_s < \frac{1}{2}$, then each signal s_i can be interpreted as informative of the borrower being of type $\theta_j, j \neq i$, where $i, j \in \{H, L\}$.

3.2.2 Strategies and payoffs

3.2.2.1 Rating Agent

In issuing a rating, the rating agents looks at the entire history of observed signals and choices till date. Let c^t denote borrower's observed choice and can take three different values –$\emptyset$ (if no lending occurs in period t), d (if default is observed in period t) and $\overline{d}$ (if repayment is observed in period t). Then, a rating agent's strategy function is given by: $R_t : \cup_{\tau=1}^{t} \left\{s^\tau, c^{\tau-1}\right\} \to [0,1]$, where c^0 is $\emptyset$. R_t is interpreted as the likelihood that the borrower is of θ_H type. His payoff in each period is assumed to be independent of his strategy.

3.2.2.2 Borrower

Recall that borrower behaves strategically only if his project succeeds. Let r_j^t denote the strategy of the borrower of type $\theta_j \in \{\theta_H, \theta_L\}$ at stage t. It is interpreted as probability of repayment by him, conditional on the project's success. Given rating R_t and the borrower's strategy r_j^t for $j \in \{H, L\}$, his expected payoffs are given by:

$$V_j\left(R_t\right) = r_j^t \left[M - \left(1 + i^t\right) + \boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right)\right] + \left(1 - r_j^t\right)\left[\left(1-\beta\right)M + \boldsymbol{E}V_j\left(R_{t+1|d}\right)\right] \tag{3.1}$$

where $R_{t+1|c^t}$ denotes the realized rating in period $t+1$ if the observed choice in period t is $c^t \in \left\{d, \overline{d}\right\}$ and $\boldsymbol{E}V_j\left(.\right)$ denotes the expected value of continuation payoffs. Depending on the signal realization $s^t \in \{s_H, s_L\}$, $R_{t+1|c^t}$ can take two values – $R_{t+1|c^t,s_j}$ and $R_{t+1|c^t,s_{i\neq j}}$ where $R_{t+1|c^t,s^{t+1}}$ denotes the realized rating in period $t+1$ when choice $c^t \in \left\{d, \overline{d}\right\}$ is observed at the end of period t and signal $s^{t+1} \in \{s_H, s_L\}$ is observed at the beginning of period $t+1$. Recall that signals are informative of the true type of the borrowers with probability p_s.

Fix $j \in \{H, L\}$, $s^{t+1} = s_j$ with probability p_s and $s^{t+1} = s_{i \neq j}$ with probability $1 - p_s$. Then $\boldsymbol{E}V_j \left(R_{t+1|c^t} \right) = p_s \boldsymbol{E}V_j \left(R_{t+1|c^t, s_j} \right) + (1 - p_s) \boldsymbol{E}V_j \left(R_{t+1|c^t, s_{i \neq j}} \right)$. If the borrower chooses *repayment* ($\bar{d}$) – which happens with probability r_j^t – he receives $M - (1 + i^t)$ in the current stage and $\boldsymbol{E}V_j \left(R_{t+1|\bar{d}} \right)$ in the future stages. Otherwise, if he chooses *default* (d) – which happens with probability $1 - r_j^t$ – he receives $(1 - \beta) M$ in the current stage and $\boldsymbol{E}V_j \left(R_{t+1|d} \right)$ in the future stages.

Let l^t be a binary choice variable which takes value 1 if the money is lent and 0 otherwise. Then, for the realized rating R_{t+1}, expected value of future continuation payoffs is given by:

$$\boldsymbol{E}V_j \left(R_{t+1} \right) \equiv \left[\theta_j V_j \left(R_{t+1} \right) + \left(1 - \theta_j \right) \boldsymbol{E}V_j \left(R_{t+2|d} \right) \right] 1 \left(l^{t+1} = 1 \right) +$$

$$\boldsymbol{E}V_j \left(R_{t+2|\emptyset} \right) 1 \left(l^{t+1} = 0 \right)$$

Positive gains can occur only if lending takes place in a period . Suppose, lending does takes places and the project is a success – which happens with probability θ_j– then borrower's payoffs are same as in equation (3.1). On the other hand, if either project fails or no lending takes place, the borrower receives no payoffs in current stage and $\boldsymbol{E}V_j \left(R_{t+2|c^t} \right)$ for $c^t \in \{d, \emptyset\}$ in future. A borrower's optimal strategy in stage t is given by:

$$r_j^t \in \arg \max_{r_j^t \in [0,1]} V_j \left(R_t \right) \text{ s.t. } \boldsymbol{E}V_j \left(R_{T+1} \right) = 0$$

3.2.2.3 Lender

While the borrower is a long lived player, the lenders are short lived and are solely concerned about the current period's payoffs. Further, they have incomplete information about the borrower's type. The rating in each period, R_t reflects their beliefs about the borrower being of high type. Based on R_t, they decide whether they would like to lend their money and determine the interest rate. Their strategy function is given by: $\left\{l^t, i^t\right\} : R_t \rightarrow \left\{\{0,1\}, \mathbb{R}^+\right\}$.

For a lender, lending is equivalent to investing in a risky project which can potentially give him a payoff higher than the risk free return $1 + i^{rf}$. If the project is funded, any of the following three outcomes can occur:

1. The project fails and the borrower defaults non-strategically - which is expected to happen with probability $R_t\left(1-\theta_H\right)+\left(1-R_t\right)\left(1-\theta_L\right)$ - in which case the lender receives 0.

2. The project succeeds and the borrower chooses to repay- which is expected to happen with probability $R_t \theta_H r_H^t+\left(1-R_t\right) \theta_L r_L^t$- in which case the lender receives the contracted amount of $1 + i^t$.

3. The project succeeds and the borrower chooses to default strategically - which is expected to happen with probability $R_t \theta_H(1-r_H^t)+(1-R_t) \theta_L(1-r_L^t)$ - in which case the lender receives an expected return of βM.

Competition among the lenders will ensure that, given R_t, the expected return from lending is same as that from investing in the risk free asset $1 + i^{rf}$. Equating the two returns gives us the interest rate choice function of the lenders as:

$$1+i^t=\beta M+\frac{(1+i^{rf})-[R_t \theta_H+(1-R_t) \theta_L] \beta M}{[R_t \theta_H r_H^t+(1-R_t) \theta_L r_L^t]} \tag{3.2}$$

Having characterized interest rate i^t as a function of $\left(R_t, r_j^t, \theta_j, \beta M\right)$ for $j \in \{H, L\}$, we make the following observations about the behavior of the interest rate:

Lemma 1 *(Optimal interest rate choice) Given M, β, θ_j and r_j^t for $\theta_j \in \{\theta_H, \theta_L\}$, the interest rate function i_t is continuous and decreasing in R_t and βM.*

A higher rating R_t indicates a greater likelihood of interacting with θ_H type of borrower who succeeds with greater probability. βM reflects the lenders payoff in the event of strategic default by the borrower. An increase in both of them indicates a lower riskiness of the loan and hence a lower interest rate.

3.2.3 Timeline of the stage game

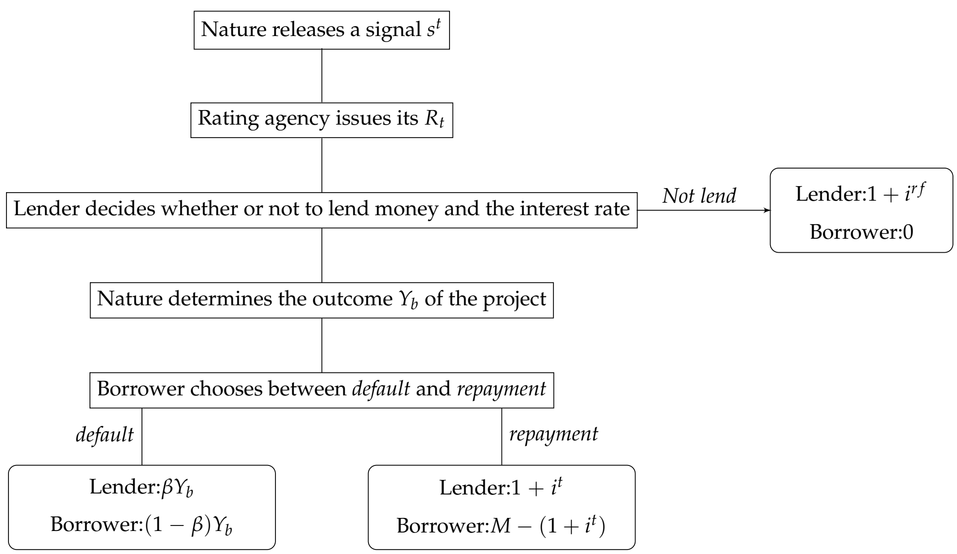


Figure 3.1: Timeline of a stage game

The timeline of the game in any period t is presented in Figure 3.1. At the beginning of each period, Nature releases an imperfectly informative signal $s^t \in \{s_H, s_L\}$, following which the rating agent issues a rating R_t. Upon observing R_t, the lender makes his lending (l^t) and interest rate (i^t) decision. If $l^t = 0$, no lending takes place and the period ends. If $l^t = 1$, lending occurs, the borrower invests the money in the project, and Nature moves to determine the outcome Y_b of the project. Based on the outcome of the project, the borrower makes his choice $c^t \in \left\{d, \overline{d}\right\}$. This choice is viewed by the lender as well as the rating agent. If the observed choice $c^t = \overline{d}$, the lender receives $Y_l = 1 + i^t$ and the borrower receives $M - \left(1 + i^t\right)$ in current stage . The period ends. If $c^t = d$, with probability β, the lender is privately able to confiscate the project's outcome. He receives an expected payoff of $Y_l = \beta Y_b$, while the borrower receives an expected payoff of $(1 - \beta)\, Y_b$ in current stage. Then the period ends.

3.3 Equilibrium

It is easy to see that there always exists a Perfect Bayesian Equilibrium for the above defined game of finite horizon. Further, the above game always admits a Markov Perfect Bayesian Equilibrium (Theorem 13.2 of Fudenberg and Tirole (1991)). We restrict our attention to the stationary Markov Perfect Bayesian Equilibrium for this dynamic game of incomplete information.

3.3.1 Definition

A stationary Markov Perfect Equilibrium is a set of stationary Markov strategies which constitute a Perfect Bayesian Equilibrium in each stage of the game. Recall that R_t plays a dual role in the model. It is not only the strategy of the rating agent but also reflects the lenders' beliefs about the borrower's type. Hence, the stationary Markov Perfect Bayesian Equilibrium of this game is defined as follows:

Definition 1 *A strategy profile* $\left\{r_H^t, r_L^t, \left\{l^t, i^t\right\}, R_t\right\}_{t=1}^{T}$ *constitutes a stationary Markov Perfect Bayesian Equilibrium if*

- *For any two* t *and* τ *(*t *not necessarily equal to* τ*), if* $R_{t-1} = R_{\tau-1}$, $r_H^{t-1} = r_H^{\tau-1}$, $r_L^{t-1} = r_L^{\tau-1}$,,$c^{t-1} = c^{\tau-1}$ *and* $s^t = s^\tau$*, then* $R_t = R_\tau$,$r_H^t = r_H^\tau$ *and* $r_L^t = r_L^\tau$.

- *The strategies* $\{r_H^t, r_L^t, \{l^t, i^t\}, R_t\}$ *are sequentially rational for all* t.

- *For all* t *and for all realized sequences of signals and observed choices* $\cup_{\tau=1}^t \{s^\tau, c^{\tau-1}\}$*, there exists a corresponding unique rating* R_t *given by*

$$R_t = \frac{q \prod_{\tau=1}^t \Pr\left(s^\tau, c^{\tau-1} | \theta = \theta_H\right)}{q \prod_{\tau=1}^t \Pr\left(s^\tau, c^{\tau-1} | \theta = \theta_H\right) + (1-q) \prod_{\tau=1}^t \Pr\left(s^\tau, c^{\tau-1} | \theta = \theta_L\right)}$$

Or equivalently,

$$R_t = \frac{R_{t-1} \Pr(s^t, c^{t-1} | \theta = \theta_H)}{R_{t-1} \Pr(s^t, c^{t-1} | \theta = \theta_H) + (1 - R_{t-1}) \Pr(s^t, c^{t-1} | \theta = \theta_L)}$$

wherever possible.

3.3.2 Characterization

In this section we characterize the player's equilibrium behavior in period t. The equilibrium choices of the strategic players are marked with an asterisks ($*$). First, we will consider a case without the rating agent. That will provide us with a benchmark to evaluate the benefits of having a rating agent.

3.3.2.1 Benchmark Case : Without Rating Agent

Consider the game specified in Section (3.2), with the slight modification that there are only two types of players in each stage - borrower and lenders. The payoffs of the borrower and lenders are identical to those described above. However, there is no rating agent now, so no additional informative signal is observed in any period and the lenders in a given period do not have any information about the borrower's default history. For the sake of notational simplicity, we would still use R_t to reflect lenders beliefs about the borrower being of type θ_H. In this case, $R_t = q$ for all $t \leq T$, and is independent of the borrowers default history $\left\{c^{\tau-1}\right\}_{\tau=1}^{t}$. The borrower's expected continuation payoffs from two choices become same and $\boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right) - \boldsymbol{E}V_j\left(R_{t+1|d}\right) = 0$. Absence of future concerns and identical present concerns makes the decision problem *ex-post* identical for all borrower types and across all time periods. Conditional on the success of the project, the borrower would choose to repay his loan if and only if the interest payment $1 + i^{*t}$ is lower than his expected payoff from default : βM. Substituting for $1 + i^{*t}$ from equation (3.2), it can be seen that there exists a threshold rating $0 < \underline{R_t^u} \equiv \left[\frac{1+i^{rf}}{\beta M} - \theta_L\right] \frac{1}{\theta_H - \theta_L} < 1$ such that, conditional on the project's success, borrowers finds it optimum to repay their loans for all higher levels of ratings. Given the borrowers' equilibrium responses, it is easy to see that the lending occurs only for $R_t \geq \underline{R_t^u}$. Hence, the equilibrium of this game can be summarized as follows:

1. $r_H^{*t} = r_L^{*t} = l^{*t} = 0$ for all t if $R_t < \underline{R_t^u}$.

2. $r_H^{*t} = r_L^{*t} = l^{*t} = 1$ and $1 + i^{*t} = \frac{1+i^{rf}}{R_t\theta_H + (1-R_t)\theta_L}$ for all t if $R_t \geq \underline{R_t^u}$.

3.3.2.2 *With Rating Agent*

For the rest of this paper, we would consider the original model specified in Section (3.2). In the presence of the rating agent, the lender's beliefs about the borrower's type are not same as the prior q any more and are affected by borrower's choices and observed signals (if the signals are informative). For a given stage t and rating R_t, either of two following two situations can arise in terms of the borrower's equilibrium behavior:

1. $\theta_H r_H^{*t} < \theta_L r_L^{*t}$

   This means that for stage t, in equilibrium, likelihood of repayment by the high type of borrower is lower than the likelihood of repayment by low type of borrower. This implies that, for stage $t+1$, the rating after default $R_{t+1|d,s^{t+1}}$ exceeds the rating after repayment, $R_{t+1|\bar{d},s^{t+1}}$ for all $s^{t+1} \in \{s_H, s_L\}$ and consequently $\boldsymbol{E}V_j\left(R_{t+1|d}\right)$ is higher than $\boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right)$. This equilibrium is possible only for $R_t \geq \underline{R_t^u}$. It was shown in subsection (3.3.2.1) that this is the region where, in the absence of rating agent, borrowers find it optimal to pay back. Hence, if this equilibrium exists, then using any historical information about the borrower unambiguously hurts the market.

2. $\theta_H r_H^{*t} \geq \theta_L r_L^{*t}$

   This means that for stage t, in equilibrium, likelihood of repayment by the θ_H type of borrower is higher than the likelihood of repayment by θ_L type of borrower. This implies that, for stage $t+1$, the rating after default $R_{t+1|d,s^{t+1}}$ is lower than the rating after repayment, $R_{t+1|\bar{d},s^{t+1}}$ for all $s^{t+1} \in \{s_H, s_L\}$ and consequently $\boldsymbol{E}V_j\left(R_{t+1|d}\right)$ is lower than $\boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right)$. As we show below, such an equilibrium always exists for all $R_t \in [0, 1]$.

For the most of this paper, we would focus on the equilibria for which $\theta_H r_H^{*t} \geq \theta_L r_L^{*t}$ holds for all stages t and defer the discussion of the second type of equilibrium to Section (3.5).

We characterize the borrowers behavior when they can make strategic choices. Conditional on the project's success, the equilibrium behavior of the borrowers is given by the following lemma.

Proposition 6 (Borrower's equilibrium behavior) *Given $R_t \in (0, 1)$, $p_s \geq \frac{1}{2}$, there exists an equilibrium such that*

1. *Both types of borrowers pool on default (d), that is,* $r_H^{*t} = r_L^{*t} = 0$ *for* $R_t < R_{t\theta_H}(p_s)$.

2. *Borrowers separate, that is,* $r_H^{*t} = 1$ *and* $r_L^{*t} \in [0,1)$ *for* $R_{t\theta_H}(p_s) \leq R_t < R_{t\theta_L}(p_s) \leq \underline{R_t^u}$

3. *Both types of borrowers pool on repayment ($\bar{d}$), that is,* $r_H^{*t} = r_L^{*t} = 1$ *for* $R_t \geq R_{t\theta_L}(p_s)$

where r_j^{*t} *solves equation (3.1) and* $R_{t\theta_j}$ *satisfies* $M - \left(1 + i^{*t}\right) + \boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right) = (1-\beta)M + \boldsymbol{E}V_j\left(R_{t+1|d}\right)$ *and* $M \geq 1 + i^{*t}$ *for* $j \in \{H, L\}$.

In equilibrium, borrowers follow a threshold strategy where they repay their loans surely for all ratings higher than a certain threshold rating. For very high levels of ratings, both borrowers pool on repayment. For very low levels of ratings, both borrowers pool on defaults. For intermediate levels of ratings, the low type of borrower does not pool with the high type of borrower. This happens because, *ceteris paribus*, a high type of borrower is more likely to succeed in his projects and also observe s_H signals. His expected value of continuation payoffs $\boldsymbol{E}V_j(.)$ is higher than that of low type of borrower. This induces him to pay a higher interest rate today. Given Lemma (1) and equation (3.1), this implies that in any stage t, the threshold rating beyond which the θ_H borrower starts repaying is at most as high as the threshold rating for θ_L borrower.

While a pure strategy equilibrium always exists for the high type of borrower, this may not be the case with the low type of borrower. The increases in the likelihood of repayments by both types of borrowers r_H^{*t} and r_L^{*t} result in a lower interest rate in current stage, however, they affect the future ratings and in turn, continuation payoffs differently. The rating after $c^t = \bar{d}$, $R_{t+1|\bar{d},s^{t+1}}$ (resp. $c^t = d$, $R_{t+1|d,s^{t+1}}$)

is increasing (resp. decreasing) in r_H^{*t}. This, in turn, implies that $\boldsymbol{E}V_j\left(R_{t+1|\bar{d},s^{t+1}}\right)$ (resp. $\boldsymbol{E}V_j\left(R_{t+1|d,s^{t+1}}\right)$) is increasing (resp. decreasing) in r_H^{*t} and decreasing (resp. increasing) in r_L^{*t}. Hence, it is in the interest of the high type of borrower to choose *repayment* ($\bar{d}$), instead of mixing. On the other hand, rating after $c^t = \bar{d}$, $R_{t+1|\bar{d},s^{t+1}}$ (resp. $c^t = d$, $R_{t+1|d,s^{t+1}}$) is decreasing (resp. increasing) in r_L^{*t}. This, in turn, implies that $\boldsymbol{E}V_j\left(R_{t+1|\bar{d},s^{t+1}}\right)$ (resp. $\boldsymbol{E}V_j\left(R_{t+1|d,s^{t+1}}\right)$) is decreasing (resp. increasing) in r_L^{*t}. Hence, by increasing r_L^{*t}, the low borrower might increase his payoffs in current stage, his future payoffs may be lower. The presence of these opposing effects may sometimes prevent the θ_L borrower from choosing a pure strategy best response.

It follows directly from Proposition (6) that the presence of a rating agent who has access to the borrower's history alters his repayment incentives. These incentives serve as a disciplining tool and encourage more frequent repayments. In this case, the usefulness of a rating agent who serves as a link between borrowing past and present is indisputable. His presence helps in alleviating the moral hazard experienced by the borrowers and discourages strategic defaults.

Given borrower's repayment behavior in Proposition (6) and interest rate characterization in equation (3.2), the lender's equilibrium behavior is given by the following lemma:

Lemma 2 (Lender's equilibrium behavior) *Given $R_t \in [0,1]$ and $p_s \geq \frac{1}{2}$, the lender finds it optimal to not lend for all $R_t < R_{t\theta_H}(p_s)$ and to lend at the interest rate given by equation (3.2) otherwise.*

For ratings $R_t < R_{t\theta_H}(p_s)$, both types of borrowers find it optimal to default, irrespective of the outcome of the project. The lender's expected payoff from lending is given by $[R_t\theta_H + (1 - R_t)\theta_L]\,\beta M$, which is lower than $1 + i^{rf}$ in these range of ratings.

For $R_t \geq R_{t\theta_H}(p_s)$, at least the high type of borrower finds it optimal to repay his loan. The jump in borrower's behavior causes the lender's payoff from lending to jump discontinuously. The interest rate, given by equation (3.2), adjusts to ensure that his return from lending is same as that from not lending. Once lending becomes optimal, it always remains an optimal choice for all higher levels of ratings as both the likelihood of repayments and the belief of lending to a high type of borrower increases.

Figure 3.2 summarizes the results of Proposition 6 and Lemma 2.

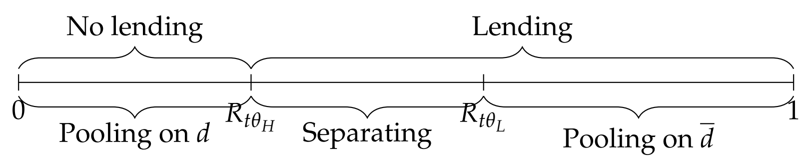


Figure 3.2: Equilibrium Behavior

Next, with the help of an example, we show that $R_{t\theta}$ is increasing in t.

Example 3 *Consider a game where borrower interacts with the lenders for $T = 10$ periods. Let the risk free return be $i^{rf} = 0.1$, the output from a successful project be $M = 10$, the probability of getting caught in case of default be $\beta = 0.3$, the likelihood of success of high type of borrower be $\theta_H = 0.9$, the likelihood of success of low type of borrower be $\theta_L = 0.1$ and the informativeness of the signal is $p_s = 0.7$. Figure 3.3 show $R_{t\theta_H}$ and $R_{t\theta_L}$ for this game:*

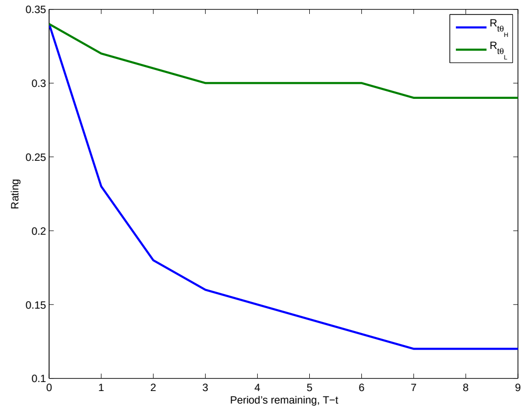


Figure 3.3: Changes in $R_{t\theta}$ with respect to t

It can be seen clearly from Figure 3.3 that $R_{t\theta_H}$ is always at high as $R_{t\theta_L}$ and both of them are increasing in t.

3.4 Impact of Information

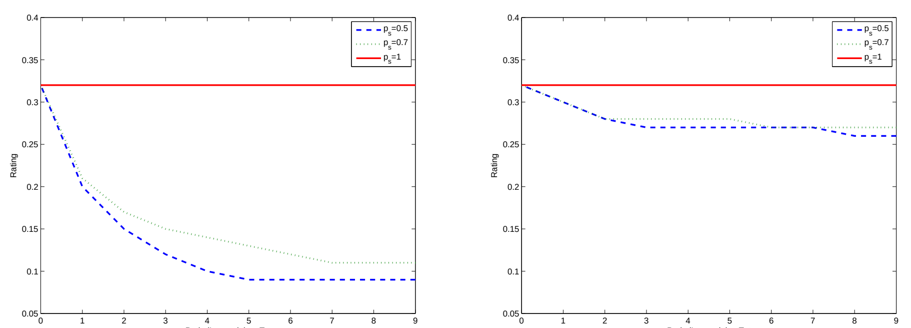
From Proposition (6), we can see that the repayment thresholds of the borrowers, $R_{t\theta}$ are a function of the informativeness of the signal p_s. In this section, we analyze the impact of increasing the precision of the signal.

3.4.1 On the borrower's behavior

We first analyze the impact of additional signals on the borrower behavior. We find that, as the signals becomes more informative, borrowers' repayment thresholds become higher. And that brings us to the central result of this paper.

Proposition 7 (Non-encouraging impact of additional information) *The repayment threshold $R_{t\theta}(p_s)$ is increasing in p_s and converges to $\underline{R_t^u}$.*

The presence of an informative signal reduces the weight assigned to the observed choices in determining future rating. Current period's choice now has a weaker influence on future continuation payoffs. Recall that a realization of signal s_H (resp. s_L) results in a higher (resp. lower) rating. As a result, *ceteris paribus*, the likelihood that a high type of borrower receives a higher rating increases in p_s. Expectations of a higher rating in future translate to a higher expected value of continuation payoff. Similarly, *ceteris paribus*, the likelihood that a low type of borrower receives a lower rating increases in p_s. Expectations of a lower rating translate to a lower expected value of continuation payoff. As a result, the marginal gain in the future continuation payoffs from repayment decline and both types of borrowers choose to repay their loan for increasingly lower levels of interest rates. It can be seen from equation (3.2) that these lower interest rates would be realized for higher levels of ratings in the current stage. Further, as $p_s \to 1$, the impact on current observable action choice goes to 0, thereby inducing borrowers to behave as they would have in the complete absence of the rating agent. Figures 3.4a and 3.4b show the behavior of $R_{t\theta_H}$ and $R_{t\theta_H}$ for Example 3 and $p_s = 0.5$, 0.7 and 1.



(a) Changes in $R_{t\theta_H}$ with respect to p_s (b) Changes in $R_{t\theta_L}$ with respect to p_s

Figure 3.4: Changes in $R_{t\theta}$ with respect to p_s

Hence, our results suggest that the presence of an informative signal increases the incidence of moral hazard among the borrowers.

3.4.2 *On the existence of market*

Market exists only if the borrower and lender interact with each other. Having fully characterized the behavior of all the players in the market, it is straightforward to analyze the impact of extra information on the behavior of the lender. Since lender moves first, his decision determines whether market exists in a stage t or not.

Proposition 8 (Frequent market failure) *The range of ratings over which lending does not happen increases in* p_s.

The above result follows directly by combining lemma (2) with the Proposition (7). The frequent defaults in the presence of informative signals translate to frequent market failure too.

3.4.3 *On the asymptotic behavior of ratings*

In this section, we analyze the asymptotic behavior of the lenders' beliefs. We find that in the long run, if the rating is based on the borrower's history, then the reputation effects diminish and the lender learns about the true type of the borrower. If the borrower is of high type, the rating converges to 1; otherwise it converges to 0. We can summarize this result as following lemma:

Lemma 3 *As* $t \rightarrow \infty$, R_t *converges to either* 0 *or* 1.

However, the additional presence of an informative signal speeds up this convergence process. The true type of the borrower gets revealed faster as the informativeness of the signal increases.

Proposition 9 (Faster convergence) *The rate of convergence of R_t increases in p_s.*

Hence, the presence of an informative signal dissipates the problem of adverse selection at a faster rate. While this is beneficial for the high type of borrower, it adversely affects the low type of borrower. However, since market quickly converges to efficient outcome, this is overall welfare enhancing.

Lastly, we analyze the impact of extra information on the welfare of the borrowers. *Ex-post*, compared to the case when no signal is observed, if the realized signal at the beginning of stage t is s_H, *ceteris paribus*, one would expect borrowers to be better off as it would result in a higher rating. Similarly, *ceteris paribus*, if the signal observed is s_L, the borrowers are expected to be worse off as the resulting rating is now lower. However, as the following discussion shows, this may not always be the case as the informativeness of the signals affects borrower's repayment behavior and in turn, lenders' decisions too.

For $R_t \in (R_{tH}(\frac{1}{2}), R_{tH}(p_s)]$, the borrowers are unambiguously worse off due to the presence of extra information as, in the presence of signal, no lending occurs in this region.

Consider $R_t \in (R_{tL}(\frac{1}{2}), R_{tL}(p_s)]$[6]. In this range of ratings both types of borrowers would have repaid with certainty in the absence of signals, conditional on success of the project. However, with the additional signal, the optimal choice of the low type of borrower changes now. This means that interest rate charged by lender t, i^t would be higher. If a given borrower chooses to repay his loan for this range of ratings, he experiences a negative impact on the current stage's payoff. However, this decline in r_L^{*t} has a positive impact on the gains in continuation payoffs, $\boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right) - \boldsymbol{E}V_j\left(R_{t+1|d}\right)$. Depending on which of the two effects

[6]Recall that $p_s = \frac{1}{2}$ corresponds to the the case where signals are completely uninformative and are as good as not observing them.

dominate, the borrower's welfare can be higher or lower in the presence of these signals.

3.5 Other Possible Equilibria

In this section, we focus on the equilibrium for which $\theta_H r_H^{*t} < \theta_L r_L^{*t}$ happens for some at least some stages t. For these class of equilibria, the observance of costly choice of repayment is associated with the greater likelihood of the borrower being of θ_L type and, *ceteris paribus*, results in a lower rating relative to default. Depending on the parameters of the model, these equilibria may arise if the following condition is satisfied:

$$\boldsymbol{E}V_H\left(R_{t+1|d}\right) - \boldsymbol{E}V_H\left(R_{t+1|\overline{d}}\right) \geq \beta M - (1+i_t^*) \geq \boldsymbol{E}V_L\left(R_{t+1|d}\right) - \boldsymbol{E}V_L\left(R_{t+1|\overline{d}}\right) \tag{3.3}$$

For these class of equilibria, $\boldsymbol{E}V_j\left(R_{t+1|d}\right) - \boldsymbol{E}V_j\left(R_{t+1|\overline{d}}\right) \geq 0$. Thus, these equilibria enhance the attractiveness of default (d) for the borrower. It can be easily seen from equation (3.2) that $1 + i_t^*$ lower than βM is possible only for $R_t \geq \underline{R_t^u} \equiv \left[\frac{1+i^{rf}}{\beta M} - \theta_L\right]\frac{1}{\theta_H - \theta_L}$. Further, for these ratings, the equilibrium interest rate is increasing in r_j^{*t}. Neither type of borrowers have an incentive to deviate. For a high type borrower, the gain in continuation payoffs after default outweighs the loss in current payoffs due to choosing this strategy. A similar reasoning applies to low type borrower, for whom the gain in current payoffs by choosing $\overline{d}$ outweighs the expected change in future payoffs. The lender holds a strong belief about the borrower being of θ_H type and expects to receive 0 with very low probability. Hence, lending still occurs for this equilibrium.

3.5.1 *Example*

Consider a two-stage interaction between borrower and lender. Let the risk free return be $i^{rf} = 0$, the output from a successful project be $M = 2$, the probability of getting caught in case of default be $\beta = 0.6$, the likelihood of success of high type of borrower be $\theta_H = 0.95$ and the likelihood of success of low type of borrower be $\theta_L = 0.4$. We use backward induction to solve for the sequential equilibrium of this game.

Stage 2: In this stage, neither of the borrowers have future concerns and they behave identically. That is, $r_H^{*2} = r_L^{*2}$. Using equations (3.2) and (B)(in Appendix A), we find that $r_H^{*2} = r_L^{*2} = 1$ for all $R_2 \geq 0.79$ and $r_H^{*2} = r_L^{*2} = 0$ for all $R_2 \leq 0.79$. Having characterized the equilibrium in Stage 2, we proceed to characterizing the equilibrium in the previous stage.

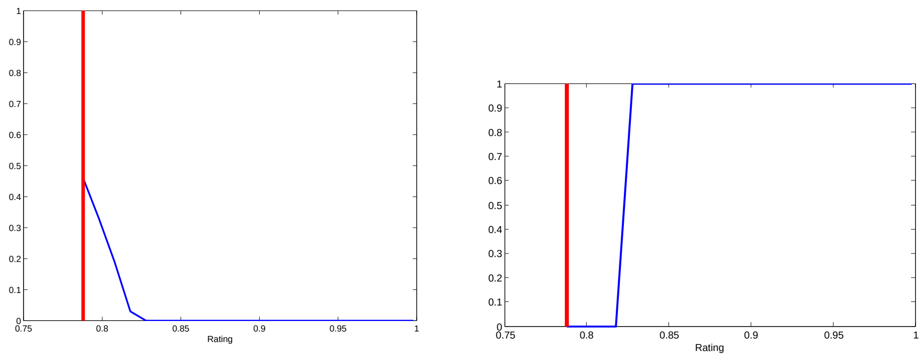
Stage 1: We observe that if $\theta_H r_H^{*1} < \theta_L r_L^{*1}$, then $R_{2|d,s^2} > R_{2|\bar{d},s^2}$. Combining equations (B) and (3.3), we find that such an equilibrium is possible only for $R_1 \geq 0.79$.

Step 1: Fix $r_H^1 = 0$ and find that r_L^{*t} for all $R_1 \geq 0.79$. Figure 3.5a shows the best response function of θ_L borrower if $r_H^1 = 0$.

Step 2: Given r_L^{*1} determined in Step 1 above, find r_H^{*1}. Figure 3.5b shows the best response function of θ_H borrower for r_L^{*1}.

It is easy to see that $r_H^{*1} = 0$ and $r_L^{*1} > 0$ for $0.79 \leq R_1 \leq 0.82$.

The possibility of existence of these equilibria is a direct implication of dropping the assumption of presence of behavioral player types. Further, as we prove in the following subsection, their existence is associated with very high levels of



(a) r_L^{*1} given $r_H = 0$ (b) r_H^{*1} given r_L^{*1}

Figure 3.5: Example

ratings R_t for which borrower finds it optimal to choose to repay even in a one-shot game. Thus, reputation concerns in this equilibrium are bad and utilizing any amount of borrower's information history unambiguously hurts the repayment incentives faced by the borrowers.

3.6 Discussion

In this section, we discuss the generalizability and extendability of our assumptions:

1. The parameter θ can be interpreted in many other ways. One possible interpretation of it is a measure of the riskiness of available projects. It can also be interpreted as the discount factor of the players. Under these interpretations, the high type of borrower is the one with access to less risky projects and with greater patience. While we assume that the failed projects yields nothing, the results would not change if the failed projects yield a positive outcome M_L as long as M_L is low enough to incapacitate the borrower from repaying his loan. The results can also be generalized to the presence of

multiple borrower types.

2. While βM captures the lenders expected payoff when there is a strategic default in an unsecured loan, it can also be understood to depict the (state-contingent) collateral of a secured loan. Thus, the model is applicable to both to secured and unsecured products. In the paper, this parameter β is assumed to be exogenously given. In the real world, the extra information (signals) are used for estimating it.

3. The interactions between lenders and borrower are modeled as short run interactions where default choice on past loan in observed before receiving any future loans. This may rarely seem to the case in the real world. Most of the real world loans are of longer terms and money is borrowed only once and follows a series of installments to be paid. While the act of borrowing may not happen repeatedly, the model is still applicable as these loans carry price triggers and a single default causes the future interest rate on the same loans to jump up.

3.7 Conclusion

The results indicate that the presence of a third party whose only function is to facilitate exchange information observed action history among short run players does not have any impact on the behavior of the players, compared to the case when players directly observe each other's experiences. However, if this third party brings in some additional information, then it alters the equilibrium but not necessarily in a positive manner. Additional independent signals reduce the significance of the information transmitted by the observable action, thereby reducing the incentive to behave nicely. The disciplinary impact of reputation further decreases as this additional information becomes more and more informative. The result has specific implications for credit markets in terms of the benefits of collecting information about the financial status-quo of the borrowers from time to time. The paper recommends that, in order to maximize repayments, more products based on the repayment history should be offered by the market.

To make the results of this paper extendable to the capital markets, we would like to consider a strategic rating agent who is not always interested in issuing an unbiased rating. We will integrate the repeated games analysis with studies in information systems to allow for alternative ways of processing information. This would be useful in ensuring wider applicability of these results.

4. MORAL HAZARD IN CREDIT MARKETS: EVIDENCE FROM PROSPER.COM

4.1 Introduction

The past decade experienced a rise in the number of consumer defaults. S&P/ Experian Consumer Credit Default Composite Index consistently rose from 1.39% in July 2004 to 5.51% in May 2009.[1] This rise in defaults was accompanied with rising concern in the lending industry that an increasing number of these defaults were strategic in nature and led to a spur in research to develop newer models to identify such risks stemming from moral hazard among borrowers.[2] In contrast, the advocates of consumer credit blamed the recession for this rise.[3] In the light of this growing literature, this study provides evidence for the presence of moral hazard in a consumer credit market. The debate on moral hazard versus negative shocks as the main driver of borrower default, or at an extreme declaration of bankruptcy, is an extensive and ongoing one between economists. In support of the moral hazard hypothesis, some of the reasons given in literature for strategic defaults include the financial benefits from bankruptcy (Fay et al. (2002), Gan et al. (2011))., very sharp decline in home equity (Foote et al. (2008), Bajari et al. (2008), Guiso et al. (2009), Bhutta et al. (2011)), lower stigma associated with default (Gross and Souleles (2002), Fay et al. (1998)) etc. There is also a parallel stream of literature claiming that consumer defaults are mainly triggered by neg-

[1] This is a proprietary index developed by S&P in collaboration with Experian and is based on the default behavior in credit cards, auto loans, first lien mortgages and second lien mortgages for a selected sample of US population. It is meant to be indicative of the consumer credit market trends.

[2] (See for example `http://www.fico.com/en/Communities/Pages/Insights.aspx` for a glimpse into research conducted by FICO about changing consumer behavior.)

[3] (See for example `http://www.time.com/time/business/article/0,8599,1876293,00.html`)

ative shocks like unemployment (Sullivan et al., 1989), divorce (Gan et al., 2011) and medical bills (Himmelstein et al. (2005)).

We use a unique data set from an online peer-to-peer lending marketplace-Prosper Marketplace Inc or more commonly known as Prosper.com. Our approach involves identifying moral hazard in a credit market by using an exogenous policy change on Prosper.com where borrowers incentives for repayments on their unsecured loans were altered by reporting their repayment behavior to TransUnion. This policy change increased the costs of defaulting in Prosper Marketplace by increasing the impact of their repayment behavior in this market on access to credit in other markets.

Post the policy change, we observed a decline in default rates, mostly for the high risk borrowers.[4] Given that there is no reason for the probability of negative shocks to change discontinuously at the time of the policy change, we attribute this ex-post decline in the defaults to the moral hazard among the borrowers.

Using time series approach on entire population. we find that prior to the change, the default rate was 9.5 percentage points higher and correspondingly, the internal rate of return on the loans was 6.6 percentage points lower. Further, to control for time varying effects such as macro economic effects, lender learning, information increments on the Prosper platform etc., we estimate a differences-in-differences model using the less treated, high credit score, low risk borrowers as the counter-factuals for the more treated, low credit score, high risk borrowers. We find that, prior to the change, relative to low risk borrowers, high risk borrowers had default rates that were larger by 9 to 11 percentage points and internal rates of return lower by 13 percentage points.

The rest of this paper is organized as follows. Section 4.2 provides background

[4] Borrowers with a credit score lower than 680 are considered high risk.

information on Prosper.com and available data. Section 4.3 contains the results and Section 4.4 provides the outcomes of falsification tests. Section 4.5 concludes. All the Tables and Figures referenced in the text are provided in Appendix C.

4.2 Background on Prosper.com

The data used in this paper comes from Prosper.com.[5] Prosper.com is an online peer-to-peer lending marketplace i.e. it serves as a platform for its lender members to make loans to its borrower members. It was opened to the public on February 13, 2006. All the loans on Prosper.com are unsecured and are for 36 months. They carry a fixed simple interest rate, are payable in monthly installments and are fully amortized. For the duration of our analysis, there was no secondary market for these loans. So once issued, the lenders completely bore any risk of default associated with them.

To become a member in this market, all individuals need to register with their name, social security number and bank account information. Additionally, the borrower members need to provide their driver's license and address. Prosper uses this information to authenticate the borrower and retrieve his credit history and score from Experian.

The borrower members can post a "listing" specifying details like loan amount requested, maximum offered interest rate, purpose of the loan, city & state of residence. They could optionally post a picture, a description about themselves along with self reported income and employment information. The listing will also contain credit information which are mostly verified by Prosper through the credit check from Experian. This includes the debt to income ratio, past and current delinquencies, available credit lines, home ownership status, recent credit in-

[5]The data were downloaded from Prosper.com web API at `http://www.prosper.com/tools/DataExport.aspx` on December 12, 2012.

quiries etc. Although Prosper observes the actual credit score of the borrower only a credit grade is posted on the listing. These credit grades are typically 40 point credit score ranges containing the actual credit score of the borrower. Within our data sample, credit grades are defined as follows: AA = scores 760 or above, A = 720-759, B = 680-719, C = 640-679, D = 600-639, E = 560-599 and HR = 520-559.

The lending process is similar to a Vickery-English auction process.[6] Once created, a listing is available for view to all the members. Additionally, members can see the percentage of loan funded, current prevailing interest rate and the number of bids placed so far. If a lender member likes a given listing, he can place a bid on the portion of requested amount that he would like to fund and the minimum acceptable interest rate (The lenders bid competitively to offer a lower interest rate. At the time of listing creation, the borrower can choose "autofunding" which means that future bidding on a listing is stopped as soon as its fully funded. Otherwise, the maximum allowable duration for the listing to remain open for bidding is 10 days.[7]. If a listing is fully funded, the interest rate of the marginal losing lender becomes the prevailing interest rate on the loan.

We observe all of the listings and loans together with the credit profile information of borrower members, since the inception of Prosper in February 2006. But we restrict our analysis to the loans that were issued between April 18, 2006 and October 16, 2008. On April 18th 2006, Prosper.com changed the level of credit profile information on the listings. (Miller, 2011) finds that this change allowed the lenders to select borrowers of better quality resulting in a drop in default rates among loans issued immediately after the change. To prevent this selection from

[6]In this type of auction, buyer (auctioneer) specifies a maximum price he is willing to pay for a single unit of a good and the sellers (bidders) compete with each other to drive the prices down. While the seller with the lowest bid sells the good, he receives a price equal to the second lowest bid.

[7]Before March 30, 2006, it was 14 days.

affecting our results, we drop all loans issued before this change. On October 16th 2008, Prosper started its process to register with SEC. As a result, it had to cease most of its operations. [8] Post registration, various changes occurred on the Prosper platform, rendering the loans issued before and after the change incomparable.[9] On February 12th 2007, Prosper made explicit changes to credit score eligibility and credit range definitions. Credit grades AA to D remained the same. The range of E grade was changed from 540-599 to 560-599. HR grade was revised from including all scores below 540 to the range of 520-559. Borrowers with no credit score information or credit score below 520 were no longer allowed to list. To account for this, we dropped all the loans with no recorded credit grade. We also dropped all the HR credit grade loans made before February 12th 2007 with either missing 20 point credit range data or a credit score below 520.

In the final data we observe 27,046 loans. Figure C.1 shows the distribution of all listings, loans and defaulted loans across the credit grades. More than half of the listings are comprised of borrowers with credit score between 520 and 600 (i.e. grades E and HR). The loans however, have a much more uniform distribution across the credit grades. As can be expected, most of the loans that default belong to the lower or riskier credit grades. The E and HR grades comprise of 20% of the loans but close to 30% of the defaults. Though the lenders only observe the credit grades, we have access to a narrower credit range of 20 points for most loans.[10]

[8] New members were no longer allowed to register. No new loans were allowed to made, while existing loans were continued to be serviced as before.

[9] Some of the changes that were made after the SEC registration include: Residents of some states in US were no longer allowed to register as members. Registered borrowers with credit scores lower than 640 were no longer allowed to post a listing. Instead of the credit scores, each listing was now assigned a proprietary 'Prosper Rating'. Lenders would bid on yield rate and not the interest rate.

[10] In the final data sample, we observe the 20 point range for 20403 loans which is around 75% of all loans. The loans with the 20 point range data missing are assigned to the lowest 20 point credit bin in the credit grade.

Details of the credit grades, the 20 point credit bins and the distribution of loans across them are also presented in Table C.1.

The descriptive statistics for the loan level control and dependent variables are presented in Table C.2. The means and standard deviations are presented separately by risk type of borrower and by the time period before and after the policy change. [11] Among the listings which materialized into loans, the low risk ones received more bids on average than the high risk ones. The difference in the number of bids is significantly larger in the post period. Unsurprisingly, the low risk borrowers pay a lower interest rate of almost 9 percentage points. Low risk borrowers are more likely to be home owners, not any more likely to post a picture on their listing or be associated with a better rated group than the high risk borrowers. Except for the bid count, the differences in other confounders between the two groups are steady over time. Finally the statistically significant differences in the outcomes of interest, the default percentage and the internal rate of return (IRR) are indicative of the effects of the policy change.

4.3 Empirical Approach and Results

4.3.1 Time Series Approach

On August 16th 2007, an announcement was made on the Prosper Discussion Forum that all historical and future repayment activity on Prosper.com would be reported to TransUnion, one of three major U.S. credit reporting agencies. [12]

[11] Borrowers with credit scores of 680 and above (credit grades AA, A and B) are considered low risk and those with scores below 680 (credit grades C, D, E and HR) are considered high risk.

[12] The announcement was part of a weekly site update. It received 2032 views and 85 replies (http://web.archive.org/web/20070916062009/http://forums.prosper.com/index.php?showforum=5). From the Aug 16th 2007 snapshot of the discussion forum, we found that the forums had 11,718 registered members at the time (http://web.archive.org/web/20070816225516/http://forums.prosper.com/index.php). This policy change was also discussed on Prosper forums hosted by a third party website (http://www.prosperreport.com/threads/3/0/6/30614.0.HTM).

The announcement reminded readers that repayment activity was already being reported to Experian.[13] It also stated that Prosper would shortly start reporting to Equifax as well. This policy change suddenly increased the penalties for default. Using this abrupt change as a natural experiment, we test for the existence of moral hazard in this credit market.

Our first empirical strategy is to employ a time series approach where we compare the default and internal rate of returns of loans made in the period prior to the treatment to those in the post period. Since the repayment behavior of past, present and future loans were to be reported to TransUnion, the treatment is retroactive. That is, the treatment applies to not only the loans originating after August 16th 2007, but also the loans active at that date, albeit at a varying degree. The loans that are 6 months old on treatment date are treated for a shorter portion of their term than loans that are 3 months old. Loans originating after the treatment date are all uniformly treated through their complete term. Figure C.2 shows default rates calculated in 30 day bins and the variation in treatment over time.

To get around the retroactive nature of the treatment, we calculate what we call ”window outcomes”. Specifically, we calculate the default rates within 6, 9 and 12 months from the date of origination. These outcomes allow us to have a period of time with no treatment. For example, Figure C.3 plots the variation in treatment over time when the outcome of interest is the default rate within 9 months of origination. The term here refers to the first 9 months since the origination of the loan. The treatment does not apply to loans that are more than 9 months old on the treatment date. Therefore, until -270 days, the fraction of term not treated is 1.

[13] Prosper was reporting repayment history to Experian from the beginning. (See `http://web.archive.org/web/20060209022718/http://www.prosper.com/public/help/topics/borrower-credit_grades.aspx`)

This fraction begins to fall linearly between -270 and 0 days to treatment. Beyond the treatment date, the fraction of the term not treated is 0.[14]

We estimate equation 4.1 below for the window and overall outcomes. The treatment is appropriately defined for the different outcomes.

$$y_{it} = \beta_0 + \beta_1 TU_t + \theta_m + \delta X_{it} + \varepsilon_{it} \tag{4.1}$$

where y_{it} is the outcome of interest. It can be a binary variable indicating default or the internal rate of return of loan i originating on date t. TU_t is the treatment variable that is coded as the fraction of the term not exposed to treatment for loans originating on date t. θ_m are month of origin fixed effects where m is the month in date t. X_{it} represents a vector of loan specific controls. The coefficient of interest is β_1 which is interpreted as the jump in the outcome generated by the absence of treatment i.e. no reporting to TransUnion.

The results are presented in Table C.3. Each cell represents a separate regression. The outcomes include default rates within the first 6, 9 and 12 months, overall default rates and internal rates of return. Column 1 shows results from a basic linear regression with no controls. Column 2 shows results after including month of origin fixed effects and column 3 is with additional loan level controls. Columns 4 and 5 present results from the controlled regressions on sample with only the high risk loans, with credit scores less than 680 and 600 respectively. Robust standard errors are presented in parenthesis.

The fully controlled regression is our preferred specification. Under this specification, all the estimates are significant at the 1% level. In the entire sample, including loans from all risk levels, the pre-treatment default rate is 9.48 percent-

[14]Treatment is defined this way to be consistent with the differences-in-differences approach described in Section 4.3.2.

age points higher. This translates to 25% more defaults when repayment activity was not being reported to TU. The recovery rate is lower in the pre-treatment period by 6.61 percentage points which is equivalent to internal rate of returns that are 40% worse on average. Borrowers are 3 percentage points or 22.6% more likely to default within first 9 months of origin prior to TransUnion reporting. By focusing on the high risk loan pools, we find the effect to be more pronounced. Within loans of credit scores of less than 680, borrowers are 26.8% more likely to default within first 9 months. When credit scores are limited to be less than 600, the default rate was 41.8% higher in the period with no reporting to TransUnion.

For these estimates to be an accurate measure of the causal effect of treatment, we need the identifying assumption that in the absence of treatment, the repayment behavior for loans made post treatment on average would be similar to that for the loans made prior to treatment. The presence of any kind of trend in repayment outcomes due to external/macro factors, gradual lender learning or changes to level of information on the Prosper platform would be problematic for this identification strategy. To overcome these shortcomings, we estimate a Differences-in-Differences model discussed in Section 4.3.2.

4.3.2 Differences-In-Differences Approach

While the policy change of reporting to TransUnion is applicable to all borrowers on Prosper.com, we argue that it has heterogeneous effects on borrowers of different risk profiles. It is reasonable to assume that the change increases the penalty for default or the incentive to repay but the mechanism is unclear. We analyze a few possible mechanisms through which this policy change might influence borrower behavior. If the announcement acted as a reminder increasing the salience of the penalties for delinquency, we think that the more financially informed low risk borrowers are less treated than the high risk borrowers. If the change simply induces the marginal effect of reporting repayments to an additional credit bureau, then we expect all the borrowers to be affected. For the borrowers who are taking the loan for debt consolidation, reporting to an additional credit bureau would increase the incentive to repay by providing them with a chance to repair their credit score from another credit bureau. We can expect such an incentive to also be greater for the high risk borrowers with lower credit scores. With this in mind, we implement a differences-in-differences model using the low risk borrowers as the control group and the high risk borrowers as the treated group. To the extent that our control group gets treated by this policy change, our diff-in-diff estimator will be attenuated towards zero.

According to Experian National Score Index, the average credit score in April 2006 for US was 678. [15] Hence, we categorized the borrowers with credit scores of 680 and above (credit grades AA, A and B) as low risk and borrowers with credit scores less than 680 (credit grades C, D, E and HR) as high risk. The default rates in grades C and below are as high as 39% and above in the period prior to treatment.[16] In our data sample, by this definition, high risk borrowers account for 85% of the listings, 60% of the loans and 70% of the defaults as shown in Figure C.1.

In order to estimate the differences-in-differences model, we divide the loans into 15 bins of mostly 20 credit score points each. The details of the credit score bins are presented in Table C.1. In the spirit of the guidelines prescribed in Bertrand et al. (2004), to account for the auto-correlation in the standard errors within the bins, we collapse the data into 2 periods, pre and post treatment.[17] Specifically,

[15] `http://www.creditsourceonline.com/credit-score-stats.html`

[16] Default rate in grade B was 30%.

[17] Since we have very few clusters, estimating the diff-in-diff at the loan level and clustering

we estimate equation 4.2 below for the window outcomes (default rates with 6, 9 and 12 months of origination) and overall default and internal rates of return.

$$y_{bt} = \beta_0 + \beta_1 \text{Pre}_t + \beta_2.\left(HighRisk * \text{Pre}\right)_{bt} + \theta_b + \delta X_{bt} + \varepsilon_{bt} \quad (4.2)$$

where t takes values 1 and 0 indicating the pre and post period relative to treatment. b represents a bin of 20 credit score points.[18] y_{bt} and X_{bt} are the means of the outcome of interest and vector of loan level controls respectively calculated for credit bin b at period t. Pre_t is a dummy variable which is equal to 1 if t is in the pre period. $HighRisk_{bt}$ is a dummy variable which is equal to 1 if the highest credit score in bin b is less than 680. θ_b are credit bin level fixed effects. β_2 is the differences-in-difference estimator of interest. It will have a reduced form interpretation as the treatment does not jump from 0 to 1 from the pre to post period.[19] We repeat the exercise with the log of the outcomes as well i.e. with y_{bt} being the log of the means of default rates within credit bin b at period t.[20]

The validity of the differences-in-differences estimate hinges on the key identifying assumption that in the absence of the policy change, the default behavior of the high risk borrowers would have trended similar to that of the low risk borrowers. Figures C.4 and C.5 provide some visual evidence to corroborate this claim. Figure C.4 shows plots of default rates within 60 day bins on either side of the treatment date, separately by risk type of the loans (borrowers). Figure C.5 is a similar graph of internal rate of returns for the two groups. From both the graphs we see that the two groups are trending fairly similar to each other in the pre-

standard errors at the individual credit score bin level is not an option.

[18] See Table 4 for details.

[19] As discussed in Section 4.3.1 on time-series the variation in treatment over time is dependent on the particular outcome.

[20] The log-linear analysis was limited to the default rates as the internal rates of return could be negative numbers.

treatment period. We perform various falsification tests, which are reported in Section 4.4, by using placebo treatment dates to further convince us of the validity of the identifying assumption.

A major concern with the time-series approach is the changing trends of other confounding factors that might affect the outcomes of interest differently in the pre period than in the post. By analysing lender portfolios over time, Freedman and Jin (2008) find that lenders learn to select better borrowers over time. Iyer et al. (2009) find that using the information posted on the listings, lenders are able to judge about 1/3 of the credit worthiness of the borrowers. They show that the resulting effect is that , lenders are able to lend at 1.06 percentage points lower rate to better borrowers within the same credit grade (of 40 credit score points) without observing the actual credit score. However, the extent to which the effects of confounders, be it the macro economic environment or lender learning over time or reducing information asymmetry, on the high risk and low risk groups trend similarly, the differences-in-differences estimator is not affected. (Miller, 2011) implements a regression discontinuity design and finds that the provision of additional credit information causes lenders to screen better borrowers, more so in the lower credit grades. [21] The drop in default rates occur predominantly in the high risk group (credit scores less than 680). We account for this in a couple of ways. Firstly, we exclude loans made before April 18th, 2006. [22] In our empirical strategy, we exploit the variation within 20 point credit bins between the pre and

[21] The Credit Grade and Debt to Income Ratio was available all along. Additional information made available included Homeownership Status, Current Delinquencies, Delinquencies Last 7 Yrs, Public Records Last 10 Yrs, Credit Inquiries, Total Credit Lines and First Credit Activity (Date)

[22] Some information increments followed. From February 12th 2007, lenders could see more credit and employment data including monetary amount delinquent, utilization rate of available revolving credit, number of public records in the last 12 months, number of current credit lines, number of open credit lines, self-reported income, employment and occupation. From October 30th, 2007 onwards, lenders could see the estimated loss probability calculated by Prosper on all of the listings. While this was not a change in information, it made the information more salient.

post period. The lenders can only observe credit grades which are 40 point bins. If additional credit information causes lenders to migrate from one 20 point bin to another, it will not affect our results. To the extent the information increments caused lenders to move from the lower end of the 20 point bin in the pre-period to the higher end in the post period, and this movement was larger for the high risk borrowers than the low risk ones, our results will be biased upwards. We do control for number of bids on the loans and interest rates, which are both indicators of lenders' assessment of borrower quality, to reduce some of the bias.

The results are presented in Tables C.4 and C.5. In both the tables, each cell represents a separate regression. The effects of the policy change on window outcomes i.e. default rates within the first 6, 9 and 12 months are presented in Panel A. The effects on overall default rates and internal rates of return are presented in Panel B. Column 1 shows results from the basic fixed effect panel model regression with no controls and Column 2 shows the same with controls. The loan level controls included are the number of bids, interest rate, borrower group rating, dummy variable for home ownership of the borrower and dummy variable for an image on the listing. [23] In Table C.4, the final column on the right presents the default rates and internal rates of return of the high risk borrowers in the pre-treatment period, which provide the baseline to calculate the percentage effect of treatment.

Table C.4 presents the differences-in-differences estimates from the linear regressions. The pre-treatment default rate is 9 to 11 percentage points higher. That is, borrowers were 20 to 25% more likely to default when repayment activity was not being reported to TransUnion.[24] In the pre-treatment period, the recovery rate

[23]The controls are also included by taking their means in the pre and post period for every credit bin.

[24]The percentage effect is calculated by using the default rates and internal rates of return of

is lower by around 13 percentage points or is 57% worse on average. Within the first 9 months from loan origination, the default rate is close to 8 percentage points or 44% more prior to TransUnion reporting. For almost all of the estimates, it is comforting to find that the controls do not make a big difference. I.e. there is no selection on observables within the high risk group over time relative to the low risk group. Robust standard errors are presented in parenthesis. Since the data are collapsed into pre and post periods, the standard errors are not required to be clustered at the credit bin level. All the estimates are significant at the 1% level.

Table C.5 presents the differences-in-differences estimates from the log linear regressions i.e. the outcome variables are logs of default rates. Robust standard errors are shown in parenthesis. The estimates in Column 1 from the OLS regression without controls, are significant at the 1% level. But the estimates in Column 2 from the regression with controls are imprecise except for the default rates within 6 months from origination. We estimate 89.1% more defaults within 9 months from origination and 38.4% more defaults overall in the period with no reporting to TransUnion.

4.4 Falsification Tests

We conduct a series of falsification tests by assigning placebo treatments in the pre and post treatment periods. The tests follow the differences-in-difference linear estimation specified in equation 4.2. We use only the pre-treatment period data for placebo dates prior to treatment and only the post-treatment period data for dates after treatment. We conduct the tests on 2 window outcomes, default rates within 6 and 9 months from origination and 1 overall outcome, the default rate. The placebo tests in the pre-treatment period are conducted only for the

high risk borrowers in the pre treatment period.

window outcomes, as there is a portion of the pre-period with no variation in treatment for these outcomes. [25] The results from these tests are presented in Table C.6. Estimates from the actual treatment are in Panel A. Estimates of placebo tests from pre-treatment period are in Panel B and those from post-treatment period are in Panel C. 12 estimates out of 50 or 24% of the estimates are significant at the 10% level. Though this number is higher than desirable, only 2 estimates out of 50 (from t+270 days) are in the same direction and at least half in magnitude as the estimate from actual treatment. All estimates from actual treatment are significant at the 1% level and only 1 placebo estimate is significant at the 1% level and is in the opposite direction.

4.5 Conclusion

In the wake of the recent recession, strategic defaults by borrowers and the existence of moral hazard are growing concerns in credit industry. Since the underlying factors leading to delinquencies are often unobserved, moral hazard is hard to identify. The sudden policy change on Prosper.com of reporting the repayment histories to TransUnion provided us with a natural experiment allowing us to test for the existence of moral hazard in this market.

Using the within credit bin variation in treatment in a differences-in-differences framework, we find that that in the period prior to the policy change, default rates were higher by around 9 to 11 percentage points and the internal rates of return were lower by 13 percentage points. With the pre treatment default rates and internal rates of return of high risk borrowers as baseline, these translate to 25% more likelihood of defaults and internal rates of return that are 40% worse in the

[25]This is shown in Figure C.3 for the default rate within 9 months from origination. From the beginning of the sample until 270 days to treatment, the treatment does not vary. Where as for the overall default rate, the treatment is continuously varying in the pre-treatment period as shown in Figure C.2.

period with no reporting to TransUnion. These results are robust to controlling for the number of bids and interest rates on the loans which should capture the lender assessment of borrower credit worthiness and there by account for lender learning over time. We conduct a series of falsification tests by assigning placebo treatments in the pre and post period. Less than 5% of the estimates are at least half in magnitude as the estimates from true treatment, in the same direction and significant at the 5% level.

We do not expect the announcement of the policy change at Prosper.com of reporting repayment histories to TransUnion to coincide with any discontinuous changes in external negative shocks probabilities. As a result we ascribe the 9 to 11 percentage point higher default rate in the period prior to reporting to the prevalence of moral hazard in this credit market. We believe that this paper contributes to the growing literature on causes behind delinquencies and bankruptcies by using a unique change with increased the penalties of defaulting and can be very informative to policy decisions on bankruptcy laws.

5. CONCLUSION

In Chapter 2, we study the problem faced by a employee when choosing whether to pursue an innovative idea as part of his employment at a firm or to form an independent start-up. We showed that employees who leave their employment to pursue new ventures tend to develop products that are weakly related to their former employers' lines of business. While increasing the level of innovation support can induce the internal exploration of a wider range of ideas, we showed that such policies may also increase employee turnover at the downstream development stage. This finding is consistent with anecdotal evidence that suggests that firms with the generous exploration policies also have a significant number of employees leaving to form new ventures. When choosing its optimal level of support, the firm in our model balances the benefits of inducing higher levels of exploration in-house with the cost of supporting this exploration activity. We find that the firm's chosen level of support increases as its relative bargaining position vis-à-vis the employee strengthens.

In Chapter 3, we analyze the impact of reducing information asymmetry in the credit markets by collecting not only a borrower's repayment history, but also other information such as past bankruptcies, public records, recent credit inquiries, etc.. We find that if a borrower expects his future lenders to base their decisions on information beyond his repayment history experiences weaker incentives to repay his current loan and becomes more likely to strategically default on his loan, especially for very high levels of interest rates. However, use of this extra information assists the lender in expeditious screening of the borrowers. The result has specific implications for credit markets in terms of the benefits of collecting information about the financial status-quo of the borrowers from time to time.

In Chapter 4, we test for the presence of moral hazard in credit market by using data from a sudden policy change of reporting the repayment histories to TransUnion in an online peer-to-peer lending market. In a differences-in-differences framework, we find that that in the period prior to the policy change, default rates were higher by around 9 to 11 percentage points and the internal rates of return were lower by 13 percentage points. This translates to 25% more chance of defaults and 40% lower internal rates of return for loans made to high risk borrowers in the pre-change period. These results are robust to controls such as the number of bids and interest rates, etc. which are expected to capture the lender assessment of borrower credit worthiness and there by account for lender learning over time.

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APPENDIX A.

PROOFS FOR CHAPTER 2

This appendix contains the proofs of all results presented in Chapter 2.

Proof of Proposition 1. We consider the case of $v_i = 0$ and $v_i = v$ separately.

1. Let $v_i = 0$. Then, the employee's outside option is common knowledge and equal to $\pi_e^E = 0$. Therefore, the employee would either choose to focus on the core task with a payoff w or develop the innovation internally depending on the negotiation outcome. Given our tie breaking rule, agreement to develop internally is possible if and only if positive bargaining surplus is available. That is, if $\pi^J = \max\{g_\Delta \Delta, 0\} \geq \pi_f^o + w = \max\{\Delta, 0\} + w$ or $\Delta > \frac{w}{g_\Delta^c - 1} > 0$. If the bargaining power is realized in the favor of the firm, then it makes an offer of w. Otherwise, if the bargaining power is realized in the favor of the employee, then he makes an offer of π_f^o. In either scenario, the offer is always accepted. For $\Delta \in (0, \frac{w}{g_\Delta^c - 1}]$, the efficient outcome is for the firm to develop independently and for the employee to focus on the core task. Thus there are no disagreements for $\Delta > 0$ and $\Delta_H(0) \equiv 0$. For $\Delta \leq 0 \equiv \Delta_L(0)$, the efficient outcome is shelving.

2. Next we consider the case when $v_i = v$. The employee makes a take-it-or-leave-it offer of π_f^o with probability $(1 - \gamma)$, which is accepted by the firm with probability 1.

   If, on the other hand, the bargaining power is realized in favor of the firm, occurring with probability γ, the firm has two options: 1) $\beta_H \alpha_e v$ accepted with probability 1 and resulting in an expected payoff of $\pi^J - \beta_H \alpha_e v$ for the firm or 2) $\beta_L \alpha_e v$ accepted with probability θ_I and resulting in an expected payoff of $(1-\theta_I)(\pi^J - \beta_L \alpha_e v) + \theta_I \pi_f^o$ for the firm. It is optimal for the firm to offer $\beta_H \alpha_e v$ if and only if its expected payoff from doing so exceeds its expected payoff from offering $\beta_L \alpha_e v$. That is,

$$\pi^J \geq \pi_f^o + \beta_L \alpha_e v + \frac{(\beta_H - \beta_L)\, \alpha_e v}{\theta_I} \tag{A.1}$$

For $\Delta \geq 0$, it is straightforward to check that the above inequality is satisfied iff $\Delta \geq \frac{\theta_I(\alpha_f v + \beta_L \alpha_e v - v) + (\beta_H - \beta_L)\alpha_e v}{\theta_I(g_\Delta^c - 1)}$. Then given that $\Delta \leq \overline{\Delta}$, we can define $\Delta_H(v, \theta_I) \equiv \min\left\{\max\left\{\frac{\theta_I(\alpha_f v + \beta_L \alpha_e v - v) + (\beta_H - \beta_L)\alpha_e v}{\theta_I(g_\Delta^c - 1)}, 0\right\}, \overline{\Delta}\right\}$. Clearly, $\Delta_H(v, \theta_I)$ is non-increasing in θ_I. Further, $\Delta_H(v, \theta_I) > 0$ if and only if $\theta_I < \frac{(\beta_H - \beta_L)\alpha_e}{1 - \alpha_f - \beta_L \alpha_e}$.

For $\Delta \leq 0$, there are two cases to consider:

- $\Delta \geq -\frac{1}{g_\Delta^s} v$, in which case equation A.1 is satisfied if and only if $\Delta \leq -\frac{\theta_I(\alpha_f v + \beta_L \alpha_e v - g_v v) + (\beta_H - \beta_L)\alpha_e v}{\theta_I(1 - g_\Delta^s)} \equiv \Delta_1(v, \theta_I)$.
- $\Delta < -\frac{1}{g_\Delta^s} v$, in which case equation A.1 is satisfied if and only if $\Delta \leq -\frac{\theta_I\left(\alpha_f v + \beta_L \alpha_e v\right) + (\beta_H - \beta_L)\alpha_e v}{\theta_I} \equiv \Delta_2(v, \theta_I)$.

Combining the inequalities above it can be verified that, given $\Delta < 0$, equation A.1 is satisfied for $\max\{\Delta_1(v, \theta_I), \Delta_2(v, \theta_I)\}$. Combining this with the fact that $\Delta \geq \underline{\Delta}$, we can define $\Delta_L(v, \theta_I) \equiv \max\{\min\{\max\{\Delta_1(v, \theta_I), \Delta_2(v, \theta_I)\}, 0\}, \underline{\Delta}\}$. Clearly, $\Delta_L(v, \theta_I)$ is non-decreasing in θ_I. Further, $\Delta_L(v, \theta_I) < 0$ if and only if $\theta_I < \frac{(\beta_H - \beta_L)\alpha_e}{1 - \alpha_f - \beta_L \alpha_e}$.

■

Proof of Corollary 1. Consider $v_i = 0$. From Proposition 1 it follows that if $\Delta >$

$\frac{w}{g_\Delta^c - 1}$, the firm will make take-it-or-leave-it offer of w to the employee with probability γ and the employee will make a take-it-or-leave-it offer to the firm of π_f^o with probability $(1-\gamma)$. Both offers will be accepted with probability 1, resulting in expected payoffs of $\pi_f^N(0, \Delta, \theta_I) = \gamma(\pi^J - w) + (1-\gamma)\pi_f^o$ and $\pi_e^N(0, \Delta, \beta, \theta_I) = \gamma w + (1-\gamma)(\pi^J - \pi_f^o)$. Otherwise,the idea is handled independently resulting in payoffs of $\pi_f^N(0, \Delta, \theta_I) = \pi_f^o = \max\{\Delta, 0\}$ and $\pi_e^N(0, \Delta, \beta, \theta_I) = \pi_e^o = w$. $\pi_f^N(0, \Delta, \theta_I)$ is strictly increasing in Δ for $\Delta > 0$ and independent of Δ for $\Delta < 0$. Similarly, $\pi_e^N(0, \Delta, \beta, \theta_I)$ is strictly increasing in Δ for $\Delta > \frac{w}{g_\Delta^c - 1}$ and independent of Δ for $\Delta < \frac{w}{g_\Delta^c - 1}$.

Now consider $v_i = v$. From Proposition 1 it follows that negotiations are always successful for $\Delta \notin (\Delta_L(v), \Delta_H(v))$ and result in $\pi_f^N(\Delta, v, \theta_I) = \gamma(\pi^J - \beta_H \alpha_e v) + (1-\gamma)\pi_f^o$ and $\pi_e^N(v, \Delta, \beta, \theta_I) = \gamma \beta_H \alpha_e v + (1-\gamma)(\pi^J - \pi_f^o)$. Otherwise, the high type employee rejects the firm's offer of $\beta_L \alpha_e v$, resulting in $\pi_f^N(\Delta, v, \theta_I) = \gamma[\theta_I \pi_f^o + (1-\theta_I)(\pi^J - \beta_L \alpha_e v)] + (1-\gamma)\pi_f^o$ and $\pi_e^N(v, \Delta, \beta, \theta_I) = \gamma \pi_e^o + (1-\gamma)(\pi^J - \pi_f^o)$. It is straightforward to see that $\pi_f^N(\Delta, v, \theta_I)$ is strictly increasing in Δ for all Δ. $\pi_e^N(v, \Delta, \beta, \theta_I)$ is strictly increasing in Δ for $\Delta > 0$ and strictly decreasing in Δ for $\Delta < 0$. ■

Proof of Proposition 2. We consider the case of $v_i = 0$ and $v_i = v$ separately.

Case I Let $v_i = 0$. Then, $\pi_e^E(v_i, \beta) = 0$ and the employee chooses between internal exploration and the core task. $\pi_e^C(L) > \pi_e^I(0, \Delta, \beta, \theta_I, L)$ if and only if $\pi_e^N > w$. By Corollary 1, this implies that internal exploration takes place if and only if $\Delta > \frac{w}{g_\Delta^c - 1}$. Otherwise, given our tie breaking-rule, the employee chooses to ignore the idea.

Case II Let $v_i = v$. Then, internal exploration payoff always exceeds the payoff from the core task and thus the employee chooses between internal and external exploration. $\pi_e^I(v,\Delta,\beta,\theta_I,L)$ is increasing in L for all β. Let $D(L,\Delta,\beta,\theta_I) \equiv \pi_e^I(0,\Delta,\beta,\theta_I,L) - \pi_e^E(v_i,\beta)$. It is straightforward to verify that $D(L,\Delta,\beta,\theta_I)$ is increasing in L, increasing in Δ for $\Delta > 0$ and decreasing in Δ for $\Delta < 0$.

Internal exploration takes place if and only if $D(L,\Delta,\beta,\theta_I) \geq 0$. Let $\bar{L}(\Delta,\beta,\theta_I)$ denote the minimum level of support that induces internal exploration, solving $D(\bar{L},\Delta,\beta,\theta_I) = 0$.

By Implicit function theorem, $\frac{d\bar{L}}{d\Delta} = -p(\bar{L})\frac{\partial\pi_e^N/\partial\Delta}{\partial D/\partial L}$. From Corollary 1, $\frac{\partial\pi_e^N}{\partial\Delta} > 0$ for $\Delta > 0$ and $\frac{\partial\pi_e^N}{\partial\Delta} < 0$ for $\Delta < 0$. Thus, $\frac{d\bar{L}}{d\Delta} < 0$ for $\Delta > 0$ and $\frac{d\bar{L}}{d\Delta} > 0$ for $\Delta < 0$.

Let

$$\Delta_c(L,v,\beta,\theta_I) = \begin{cases} 0 & \text{if} \quad L > \bar{L}(0,\beta,\theta_I) \\ \bar{L}^{-1}(\Delta) & \text{if} \quad L \in \left[\bar{L}(\overline{\Delta},\beta,\theta_I), \bar{L}(0,\beta,\theta_I)\right] \\ \overline{\Delta} & \text{if} \quad L < \bar{L}(\overline{\Delta},\beta,\theta_I) \end{cases} .$$

$$\Delta_s(L,v,\beta,\theta_I) = \begin{cases} \underline{\Delta} & \text{if} \quad L < \bar{L}(\underline{\Delta},\beta,\theta_I) \\ \bar{L}^{-1}(\Delta) & \text{if} \quad L \in [\bar{L}(\underline{\Delta},\beta,\theta_I), \bar{L}(0,\beta,\theta_I)] \\ 0 & \text{if} \quad L > \bar{L}(0,\beta,\theta_I) \end{cases}$$

For a given L, internal exploration occurs if and only if $\Delta \geq \Delta_c(L,v,\beta,\theta_I)$ or $\Delta \leq \Delta_s(L,v,\beta,\theta_I)$ where $\frac{\partial\Delta_c}{\partial L} = \frac{1}{\partial\bar{L}/\partial\Delta} < 0$ and $\frac{\partial\Delta_s}{\partial L} = \frac{1}{\partial\bar{L}/\partial\Delta} > 0$. By Implicit Function Theorem, $\frac{\partial\Delta_c}{\partial\beta} = -\frac{p(L)\frac{\partial\pi_e^N}{\partial\beta} - p_o v}{\partial D/\partial\Delta}$. Note that $D(L,\Delta_c,\beta,\theta_I) = 0$ implies that $p_o\beta v > p(L)\pi_e^N$. Moreover, $p(L)\frac{\partial\pi_e^N}{\partial\beta} \leq p(L)\alpha_e v < p_o v$. Therefore, $\frac{\partial\Delta_c}{\partial\beta} > 0$ implying that $\Delta_c(L,v,\beta_L,\theta_I) \leq \Delta_c(L,v,\beta_H,\theta_I)$ for all θ_I. Analogously, $\frac{\partial\Delta_s}{\partial\beta} = -\frac{p(L)\frac{\partial\pi_e^N}{\partial\beta} - p_o v}{\partial D/\partial\Delta} < 0$, implying that $\Delta_s(L,v,\beta_L,\theta_I) \geq \Delta_s(L,v,\beta_H,\theta_I)$ for all θ_I.

It remains to determine θ_I^*. By Corollary 1, $\pi_e^N(L, v, \beta_H)$ is independent of θ_I. Therefore, $\Delta_s(L, v, \beta_H)$ and $\Delta_c(L, v, \beta_H)$ will be independent of θ_I. Since $\Delta_c(L, v, \beta_L, \theta_I) \leq \Delta_c(L, v, \beta_H)$ and $\Delta_s(L, v, \beta_L, \theta_I) \geq \Delta_s(L, v, \beta_H)$for all θ_I, both types choose internal exploration for $\Delta \notin (\Delta_s(L, v, \beta_H), \Delta_c(L, v, \beta_H))$ and thus $\theta_I^* = q$. For $\Delta \in (\Delta_s(L, v, \beta_H), \Delta_c(L, v, \beta_H))$ the high type always explores externally. Given $\theta_I = 0$, low type of employee chooses internal exploration if and only if $\Delta \notin (\Delta_s(L, v, \beta_L, 0), \Delta_c(L, v, \beta_L, 0))$. Therefore, if $\Delta \in (\Delta_s(L, v, \beta_H), \Delta_s(L, v, \beta_L, 0)]$ or $\Delta \in [\Delta_c(L, v, \beta_L, 0), \Delta_c(L, v, \beta_H))$, the low type explores internally and by Bayes' rule $\theta_I^* = 0$.

Finally, for $\Delta \in (\Delta_s(L, v, \beta_L, 0), \Delta_c(L, v, \beta_L, 0))$, the only possible equilibrium is for both types to explore externally. Otherwise, if θ_I is such that $\Delta \notin (\Delta_s(L, v, \beta_L, \theta_I), \Delta_c(L, v, \beta_L, \theta_I))$, then by Bayes' rule $\theta_I = 0$, resulting in a contradiction. An off-equilibrium belief $\theta_I = 0$ in this region guarantees no deviation incentives by the low type.

Let $\Delta_s^*(L, v, \beta_H) = \Delta_s(L, v, \beta_H)$, $\Delta_c^*(L, v, \beta_H) = \Delta_c(L, v, \beta_H)$,

$\Delta_s^*(L, v, \beta_L) = \Delta_s(L, v, \beta_L, \theta_I^*)$, $\Delta_c^*(L, v, \beta_L) = \Delta_c(L, v, \beta_L, \theta_I^*)$. This completes the proof.

■

Proof of Proposition 3. The probability of internal exploration is given by

$$\begin{aligned} W(L) &= \left[(1-\psi)\left(1 - F(\frac{w}{g_\Delta^c - 1}|0)\right)\right] + \\ &\quad +\psi \sum_\beta \Pr(\beta)\left[1 - \left(F(\Delta_c^*(L, v, \beta)|v) - F(\Delta_s^*(L, v, \beta)|v)\right)\right]. \end{aligned}$$

Then, $\frac{dW}{dL} = \psi \sum_\beta \Pr(\beta) \left[f(\Delta_s^*)\frac{\partial \Delta_s^*(L,v,\beta)}{\partial L} - f(\Delta_c^*)\frac{\partial \Delta_c^*(L,v,\beta)}{\partial L}\right] > 0$ since by Proposition 2 $\frac{\partial \Delta_s^*(L,v,\beta)}{\partial L} \geq 0$ and $\frac{\partial \Delta_c^*(L,v,\beta)}{\partial L} \leq 0$.

By Proposition 2, $\theta_I \leq q$. Proposition 1 then implies that downstream disagreements are not possible for $\theta_I \geq q \geq \frac{(\beta_H-\beta_L)\alpha_e}{1-\alpha_f-\beta_L\alpha_e}$ since then $\Delta_L(v,\theta_I) = \Delta_H(v,\theta_I) = 0$. For $q < \frac{(\beta_H-\beta_L)\alpha_e}{1-\alpha_f-\beta_L\alpha_e}$, if $\Delta \in (\Delta_s^*(L,v,\beta_H), \Delta_c^*(L,v,\beta_H))$, by Proposition 2 $\theta_I^* = 0$. In this case, $\Delta_L(v,0) = \Delta_H(v,0) = 0$ (see proof of Proposition 1). Therefore, a necessary condition for downstream disagreements is $\Delta \notin (\Delta_s^*(L,v,\beta_H), \Delta_c^*(L,v,\beta_H))$. In this case, $\theta_I^* = q$ and $q < \frac{(\beta_H-\beta_L)\alpha_e}{1-\alpha_f-\beta_L\alpha_e}$ guarantees $\Delta_L(v,\theta_I) < 0$ and $\Delta_H(v,\theta_I) > 0$. Downstream disagreements occur if and only if $\Delta \in (\Delta_L(v,q), \Delta_s^*(L,v,\beta_H)) \cup (\Delta_c^*(L,v,\beta_H), \Delta_H(v,q))$. By Proposition 2, $\Delta_s^*(L,v,\beta_H)$ is increasing in L and $\Delta_c^*(L,v,\beta_H)$ is decreasing in L. Therefore, there exists $\tilde{L}$ such that the region of downstream disagreements is non-empty and increasing in L. ■

Proof of Proposition 4. Suppose that L^* is an interior optimum. Let $S_f(\Delta, v_i, \beta)$ denote the firm's surplus from internal exploration of the idea. The first order derivative of the optimization problem expressed in Equation 2.1 is given as below:

$$FOC(L) = \left\{ \begin{array}{c} \sum_\beta \Pr(\beta) \sum_{v_i} \Pr(v_i) \left[\begin{array}{c} E\left(\frac{\partial S_f(\Delta, v_i, \beta, L)}{\partial L} | \Delta \notin (\Delta_s(.), \Delta_c(.)) \right) \\ + S_f(\Delta_s, v_i, \beta, L) f(\Delta_s | v_i) \frac{d\Delta s}{dL} - \\ S_f(\Delta_c, v_i, \beta, L) f(\Delta_c | v_i) \frac{d\Delta c}{dL} \end{array} \right] \\ -1 + \Pr(v) \left[F(\Delta_c(v, L, \beta)) - F(\Delta_s(v, L, \beta)) \right] - \\ L \Pr(v) \left[f(\Delta_c(.)|v) \frac{d\Delta_c}{dL} - f(\Delta_s(.)|v) \frac{d\Delta_s}{dL} \right] \end{array} \right\}$$

Then, L^* solves $FOC(L^*) = 0$. Using implicit function theorem on equation 2.2, we obtain:

$$\frac{dL^*}{d\gamma} = -\frac{\frac{\partial FOC(L^*)}{\partial \gamma} + \frac{\partial FOC(L^*)}{d\Delta_s} \cdot \frac{\partial \Delta_s^*}{\partial \gamma} + \frac{\partial FOC(L^*)}{d\Delta_c} \cdot \frac{\partial \Delta_c^*}{\partial \gamma}}{\frac{d^2 FOC(L^*)}{dL^2}}$$

Since $\frac{d^2\Pi}{dL^2} < 0, \frac{dL^*}{d\gamma} \overset{sign}{=} \frac{\partial FOC(L^*)}{\partial\gamma} + \frac{\partial FOC(L^*)}{d\Delta_s}.\frac{\partial\Delta_s}{\partial\gamma} + \frac{\partial FOC(L^*)}{d\Delta_c}.\frac{\partial\Delta_c}{\partial\gamma}$.

The direct effect of change on γ is given by:

$$\frac{\partial FOC(L^*)}{\partial\gamma} = \sum_{\beta} \Pr(\beta) \sum_{v_i} \Pr(v_i) \left[\begin{array}{c} E\left(\frac{\partial^2 S_f(.)}{\partial\gamma\partial L} | \Delta \notin (\Delta_s(.), \Delta_c(.)) \right) + \\ \frac{\partial S_f(.)}{\partial\gamma} f(\Delta_s|v_i) \frac{d\Delta_s}{dL} - \frac{\partial S_f(.)}{\partial\gamma} f(\Delta_s|v_i) \frac{d\Delta_c}{dL} \\ +S_f(.) f(\Delta_s|v_i) \frac{d^2\Delta s}{d\gamma dL} - S_f(.) f(\Delta_c|v_i) \frac{d^2\Delta c}{d\gamma dL} \end{array} \right]$$

It is straightforward to verify that $\frac{\partial^2 S_f(\Delta, v_i, \beta, L)}{\partial\gamma\partial L} > 0$, $\frac{\partial S(\Delta, v_i, \beta, L)}{\partial\gamma} > 0$ and $\frac{d^2\Delta s}{d\gamma dL} = 0$, which results in $\frac{\partial FOC(L^*)}{\partial\gamma} > 0$. The derivatives of FOC with respect to Δ_s and Δ_c is given by:

$$\frac{dFOC(L^*)}{d\Delta_s} = \left[\sum_{\beta} \Pr(\beta) \sum_{v_i} \Pr(v_i) \left[2\frac{dS_f(\Delta_s, v_i, \beta, L)}{dL} f(\Delta_s|v) \right] - \Pr(v) f(\Delta_s|v) \right]$$

$$\frac{dFOC(L^*)}{d\Delta_c} = \left[\Pr(v) f(\Delta_c|v) - \sum_{\beta} \Pr(\beta) \sum_{v_i} \Pr(v_i) \left[2\frac{dS_f(\Delta_c, v_i, \beta, L)}{dL} f(\Delta_c|v) \right] \right]$$

Moreover, it is straightforward to verify that both $\frac{dS_f(\Delta_s, v_i, \beta, L)}{dL}$ and $\frac{dS_f(\Delta_c, v_i, \beta, L)}{dL}$ are negative. It follows from implicit function theorem that $\frac{\partial\Delta}{\partial\gamma} = -\frac{\frac{\partial S_e}{\partial\gamma}}{\frac{\partial S_e}{\partial\Delta}}$. It is straightforward to verify that $S_e(L, \Delta, \beta, \theta_I)$ is decreasing in γ, increasing in Δ for $\Delta > 0$ and decreasing in Δ for $\Delta < 0$. Hence, $\frac{\partial\Delta_c^*}{\partial\gamma} > 0$ and $\frac{\partial\Delta_s^*}{\partial\gamma} < 0$. Therefore, $\frac{\partial FOC(L^*)}{d\Delta_s}.\frac{\partial\Delta_s^*}{\partial\gamma} > 0$ and $\frac{\partial FOC(L^*)}{d\Delta_c}.\frac{\partial\Delta_c^*}{\partial\gamma} > 0$, completing the proof.

An analogous proof can be written for α_f and α_e. ■

APPENDIX B.

PROOFS FOR CHAPTER 3

This appendix contains the proofs of all results presented in Chapter 3.

Proof of Lemma 1. In determining the interest rate, the lender equates his expected return from lending to the return from investing in risk-free asset. That is, the following condition holds:

$$\left[R_t\theta_H r_H^t + (1-R_t)\,\theta_L r_L^t\right](1+i_t^*) +$$

$$\left[R_t\theta_H\left(1-r_H^t\right) + (1-R_t)\,\theta_L\left(1-r_L^t\right)\right]\beta M = \left(1+i^{rf}\right)$$

Taking total differentials of the above equation gives us:

$$\left[R_t\theta_H r_H^t + (1-R_t)\,\theta_L r_L^t\right] d\,(1+i_t^*) +$$

$$\left[\left(\theta_H r_H^t - \theta_L r_L^t\right)(1+i_t^* - \beta M) + (\theta_H - \theta_L)\,\beta M\right] dR_t = 0$$

Substituting for $1+i_t^*$ from equation (3.2) it can be shown that $(\theta_H r_H - \theta_L r_L)(1+i_t^* - \beta M) + (\theta_H - \theta_L)\beta M$ can be simplified to $\theta_H r_H^t[1+i^{rf} - \theta_L\beta M] + \theta_L r_L^t[\theta_H\beta M - (1+i^{rf})] \geq 0$. Combining this with the fact that $R_t\theta_H r_H^t + (1-R_t)\,\theta_L r_L^t \geq 0$, the negative relation between rating and interest rate is easy to see.

Again, differentiating equation (3.2) with respect to βM gives us:

$$\frac{d}{d\beta M}\left(1+i(R_t)\right) = \frac{-[R_t\theta_H(1-r_H^t) + (1-R_t)\theta_L(1-r_L^t)]}{[R_t\theta_H r_H^t + (1-R_t)\theta_L r_L^t]} \leq 0$$

Since equation (3.2) is a polynomial function, it is continuous in all its parameters.

■

Proof of Proposition 6. We find that $R_{t+1|d,s^t} - R_{t+1|\bar{d},s^t} \overset{sign}{=} (\theta_L r_L^t - \theta_H r_H^t)$ and hence, $\boldsymbol{E}V_\theta\left(R_{t+1|d}\right) - \boldsymbol{E}V_\theta\left(R_{t+1|\bar{d}}\right) \overset{sign}{=} (\theta_L r_L^t - \theta_H r_H^t)$.

Step 1: $r_H^{*t} = r_L^{*t} = 1$ **is always an equilibrium for** $R_t \geq \underline{R_t^u}$**.**

Proof: For $R_t \geq \underline{R_t^u}$, $\beta M - (1+i^*) \geq 0$ with the inequality being strict for $R_t > \underline{R_t^u}$. Also, $r_H^{*t} = r_L^{*t} > 0$ implies that $\theta_L r_L^{*t} < \theta_H r_H^{*t}$ and hence $[\boldsymbol{E}V_\theta\left(R_{t+1|d}\right) - \boldsymbol{E}V_\theta\left(R_{t+1|\bar{d}}\right)] < 0$. Then $\beta M - (1+i^*) + \boldsymbol{E}V_\theta\left(R_{t+1|\bar{d}}\right) - \boldsymbol{E}V_\theta\left(R_{t+1|d}\right) \geq 0$ and neither of the borrowers would have an incentive to deviate.

Recall that in a one shot game, conditional on project's success, borrowers find it optimal to not default on their loan if current rating $R_t \geq \underline{R_t^u} \equiv \left[\frac{1+i^{rf}}{\beta M} - \theta_L\right]\frac{1}{\theta_H - \theta_L}$. It is easy to see that this will continue to be on optimal strategy for the repeated game too.

Step 2: $r_H^{*t} = r_L^{*t} = 0$ **is always an equilibrium for** $R_t < \underline{R_t^u}$**.**

Proof: For $R_t < \underline{R_t^u}$, $\beta M - (1+i^*) < 0$. Also, $r_H^{*t} = r_L^{*t} = 0$ implies that $\theta_L r_L^{*t} = \theta_H r_H^{*t} = 0$ and hence $\left[\boldsymbol{E}V_j\left(R_{t+1|d}\right) - \boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right)\right] = 0$. Then $\beta M - (1+i^*) + \boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right) - \boldsymbol{E}V_j\left(R_{t+1|d}\right) < 0$ and neither of the types of borrowers would have an incentive to deviate.

Step 3: There exists no equilibrium for which $0 < r_H^{*t} < 1$**.**

It can be seen from previous discussion that $0 < r_H^* < 1$ is possible only if $R_t \leq \underline{R_t^u}$. If $0 < r_H^* < 1$, then it satisfies $\beta M - \left(1 + i^*_{r_H,r_L}\right) = \boldsymbol{E}V_H\left(R_{t+1|d}\right) - \boldsymbol{E}V_H\left(R_{t+1|\bar{d}}\right)$. Since, $\frac{d\boldsymbol{E}V_H\left(R_{t+1|d}\right)}{dr_H} \leq 0$ and $\frac{d\boldsymbol{E}V_H\left(R_{t+1|\bar{d}}\right)}{dr_H} \geq 0$, the right hand side of this expression is decreasing in r_H. Since interest rate is increasing in r_H^{*t} for $R_t \leq \underline{R_t^u}$, at $r_H^* = 1$, $\beta M - \left(1 + i^*_{1,r_L}\right) > \boldsymbol{E}V_H\left(R_{t+1|d}\right) - \boldsymbol{E}V_H\left(R_{t+1|\bar{d}}\right)$ holds.

We proceed towards showing that for $R_t < \underline{R_t^u}$ there is a possibility of existence of another equilibrium where $r_j^{*t} > 0$. The borrower's optimal strategy maximizes expression (3.1) given as under:

$$M - \left(1 + i^{*t}\right) + \boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right) \geq (1-\beta)\,M + \boldsymbol{E}V_j\left(R_{t+1|d}\right)$$

Since i_t^* is decreasing in R_t, a sufficient condition for the existence of such an equilibrium requires $\boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right) - \boldsymbol{E}V_j\left(R_{t+1|d}\right)$ to be increasing in R_t. If this condition is violated, it is possible that such an equilibrium does not exist, in which case, $R_{t\theta_H}(p_s) = R_{t\theta_L}(p_s) = \underline{R_t^u}$. For the rest of the analysis, we assume that this condition is satisfied and such an equilibrium exists. Then we can say the following:

Step 4: If, given R'_t, there exists an equilibrium such that $r_j^{*t}(R'_t) = 1$, then there exists an equilibrium such that $r_j^{*t}(R_t) = 1$ for all $R_t \geq R'_t$.

Proof: Consider $\theta = \theta_H$. Let R'_t denote the rating for which an equilibrium with $p_H^{*t}(R'_t) = 1$ exists. Since $r_H^{*t}(R'_t) = 1$, the following condition is satisfied at R'_t:

$$\beta M - \left(1 + i^*\left(R'_t\right)_{1,r_L}\right) > \boldsymbol{E}V_H\left(R'_{t+1|d}\right)_{|(1,r_L)} - \boldsymbol{E}V_H\left(R'_{t+1|\bar{d}}\right)_{|(1,r_L)} \qquad \text{(B.1)}$$

Consider $R_t > R'_t$. The payoff to the high type of borrower from choosing

$r_H(R_t) = 1$ is given by:

$$\begin{aligned}
& \beta M - \left(1 + i^*(R_t)_{1,r_L}\right) \\
> \; & \beta M - \left(1 + i^*(R_t')_{1,r_L}\right) \text{ (Because } i^* \text{ is decreasing in } R_t\text{)} \\
> \; & \boldsymbol{E}V_H\left(R'_{t+1|d}\right)_{|(1,r_L)} - \boldsymbol{E}V_H\left(R'_{t+1|\bar{d}}\right)_{|(1,r_L)} \text{ (From Equation B.1)} \\
> \; & \boldsymbol{E}V_H\left(R_{t+1|d}\right)_{|(1,r_L)} - \boldsymbol{E}V_H\left(R_{t+1|\bar{d}}\right)_{|(1,r_L)}
\end{aligned}$$

An analogous proof would hold for $\theta = \theta_L$.

Notice that equation 3.1 is strictly increasing in R_t and would be satisfied with equality for a unique value of R_t. The level of rating for this would happen is denoted by $R_{t\theta}(p_s)$. Lastly, we prove that $R_{t\theta_H}(p_s) \leq R_{t\theta_L}(p_s)$. Now there are two possibilities here. First, $\boldsymbol{E}V_H\left(R_{t+1|\bar{d}}\right) - \boldsymbol{E}V_H\left(R_{t+1|d}\right) \leq \boldsymbol{E}V_L\left(R_{t+1|\bar{d}}\right) - \boldsymbol{E}V_L\left(R_{t+1|d}\right)$ in which $r_L^{*t} = 0$ for all $R_t < R_{t\theta_H}(p_s)$ and hence $R_{t\theta_H}(p_s) = R_{t\theta_L}(p_s)$. The other possibility is $\boldsymbol{E}V_H\left(R_{t+1|\bar{d}}\right) -$
$\boldsymbol{E}V_H\left(R_{t+1|d}\right) > \boldsymbol{E}V_L\left(R_{t+1|\bar{d}}\right) - \boldsymbol{E}V_L\left(R_{t+1|d}\right) \geq 0$. ■

Proof of Lemma 2. It can be seen from Lemma (6) that borrower's repayment probabilities $r_H^{*t} = r_L^{*t} = 0$ for $R < R_{t\theta_H}(p_s) \leq \underline{R_t^u} \equiv \left[\frac{1+i^{rf}}{\beta M} - \theta_L\right]\frac{1}{\theta_H - \theta_L}$. Then the lenders' payoff from lending is $[R_t\theta_H + (1-R_t)\theta_L]\beta M < 1 + i^{rf}$ - the return from not lending. Hence, no lending would occur.

It is easy to see that lending would be an optimal choice for $R_t \geq R_{t\theta_H}(p_s)$ as the interest rate given by equation (3.2) would ensure that the lender is indifferent between lending and not lending. ■

Proof of Proposition 7.

The following two situations can arise:

Case 1 $R_t = 0$ or 1. Then $R_{t+1|d,s^t} = R_{t+1|\bar{d},s^t} = R_t$ for $s^t \in \{s_H, s_L\}$. Then,

$V_j\left(R_{t+1|d,s^t}\right) = V_j\left(R_{t+1|\overline{d},s^t}\right)$ and hence, $\boldsymbol{E}V_j\left(R_{t+1|\overline{d}}\right) - \boldsymbol{E}V_j\left(R_{t+1|d}\right) = 0$. Clearly, $1 + i^*_{t\theta}$ becomes independent of p_s.

Case 2 $0 < R_t < 1$.Recall that for $\theta \in \{\theta_H, \theta_L\}$, $R_{t\theta}(p_s)$ solves

$$\beta M - \left(1 + i^*\left(R_t\right)_{r_H,r_L}\right) \geq \boldsymbol{E}V_j\left(R_{t+1|d}\right)_{|(r_H,r_L)} - \boldsymbol{E}V_j\left(R_{t+1|\overline{d}}\right)_{|(r_H,r_L)} \tag{B.2}$$

At $R_{t\theta_H}(p_s)$, $r_H = 1$ and $r_L = 0$. The realized rating after observing a not default ($\overline{d}$) in stage t is $R_{t+1|\overline{d},s^t} = 1$ for all $s^t \in \{s_H, s_L\}$. Clearly, $R_{t+1|\overline{d},s^t}$ and hence $\boldsymbol{E}V_H\left(R_{t+1|\overline{d}}\right)$ is independent of p_s . The realized ratings after observing a default (d), conditional on the observed signal, are given by: $R_{t+1|d,s_H} = \frac{p_s(1-\theta_H)R_t}{p_s(1-\theta_H)R_t+(1-p_s)(1-R_t)}$ and $R_{t+1|d,s_L} = \frac{(1-p_s)(1-\theta_H)R_t}{(1-p_s)(1-\theta_H)R_t+p_s(1-R_t)}$. It is easy to see that $R_{t+1|d,s_H}$ is increasing in p_s and $R_{t+1|d,s_L}$ is decreasing in p_s. Thus, $\boldsymbol{E}V_H\left(R_{t+1|d}\right)$ is increasing in p_s. Since, the left hand side of equation (B.2) is increasing in R_t and the right hand side is decreasing in R_t, the level of rating $R_{t\theta_H}(p_s)$ which satisfies equation (B.2) is increasing in p_s.

At $R_{t\theta_L}(p_s)$, $r_H = 1$ and $r_L = 1$. It can be seen from the previous argument, that it would be suffice to show that the right hand side of the equation (B.2) is increasing in p_s for $\theta = \theta_L$ also. Now the right hand side of the equation (B.2) can be rewritten as

$$p_s\left[V_L\left(R_{t+1|d,s_L}\right) - V_L\left(R_{t+1|\overline{d},s_L}\right)\right] + (1-p_s)\left[V_L\left(R_{t+1|d,s_H}\right) - V_L\left(R_{t+1|\overline{d},s_H}\right)\right] \tag{B.3}$$

Given R_t, $\left|V_L\left(R_{t+1|d,s_L}\right) - V_L\left(R_{t+1|\overline{d},s_L}\right)\right| > \left|V_L\left(R_{t+1|d,s_H}\right) - V_L\left(R_{t+1|\overline{d},s_H}\right)\right|$ holds (Because of the concavity of the $V_L(.)$ function). It can be shown that for all

$R_t \leq \underline{R} \equiv \frac{1}{\theta_H - \theta_L}\left[\frac{1+i^{rf}}{\beta M} - \theta_L\right]$ and for all $\theta_L \in \left[1-\theta_H, \frac{1+i^{rf}}{M}\right)$, $R_{t+1|d,s_L} - R_{t+1|\bar{d},s_L}$ is increasing in p_s and hence $V_L\left(R_{t+1|d,s_L}\right) - V_L\left(R_{t+1|\bar{d},s_L}\right)$ is also increasing in p_s. Then $\boldsymbol{E}V_j\left(R_{t+1|d}\right)_{|(r_H,r_L)} - \boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right)_{|(r_H,r_L)}$ increases in p_s.

As p_s converges to 1, $R_{t+1|d,s_H} - R_{t+1|\bar{d},s_H} \to R_{t+1|d,s_L} - R_{t+1|\bar{d},s_L} \to 0$ and hence $\boldsymbol{E}V_j\left(R_{t+1|\bar{d}}\right) - \boldsymbol{E}V_j\left(R_{t+1|d}\right) \to 0$. Since i^* is continuous in R_t, this implies that as $p_s \to 1$, $R_{t\theta}(p_s) \to \underline{R_t^u}$. ■

Proof of Proposition 8.

The result follows by combining Lemma (2) and Proposition (7). ■

Proof of Lemma 3. The rating R_t in stage t is given by:

$$R_t = \frac{q\prod_{\tau=1}^{t}\Pr\left(s^\tau, c^{\tau-1}|\theta=\theta_H\right)}{q\prod_{\tau=1}^{t}\Pr\left(s^\tau, c^{\tau-1}|\theta=\theta_H\right) + (1-q)\prod_{\tau=1}^{t}\Pr\left(s^\tau, c^{\tau-1}|\theta=\theta_L\right)}$$

Since s^t and c^{t-1} are independent of each other, this can be rewritten as

$$R_t = \frac{1}{1+\frac{1-q}{q}.\prod_{\tau=1}^{t}\frac{\Pr(s^t|\theta=\theta_L)}{\Pr(s^t|\theta=\theta_H)}.\prod_{\tau=1}^{t}\frac{\Pr\left(c^{t-1}|\theta=\theta_L\right)}{\Pr\left(c^{t-1}|\theta=\theta_H\right)}}$$

Let us define $\rho_{1t} \equiv \prod_{\tau=1}^{t}\frac{\Pr\left(s^t|\theta=\theta_L\right)}{\Pr(s^t|\theta=\theta_H)}$ and $\rho_{2t} \equiv \prod_{\tau=1}^{t}\frac{\Pr\left(c^{t-1}|\theta=\theta_L\right)}{\Pr\left(c^{t-1}|\theta=\theta_H\right)}$.

1. Let η_{1t} denote the number of times the observed signal $s^\tau = s_H$ for all $\tau \leq t$. Then signal $s^t = s_L$ is observed in $t - \eta_{1t}$ periods. Since the observed signals s^t are independently and identically distributed across time, the past history of signals can be summarized by a number reflecting the numbers of times a given signal is observed. ρ_{1t} can be rewritten as:

$$\rho_{1t} = \left[\frac{p_s^{1-\frac{\eta_t}{t}}(1-p_s)^{\frac{\eta_t}{t}}}{p_s^{\frac{\eta_t}{t}}(1-p_s)^{1-\frac{\eta_t}{t}}}\right]^t = \left[\frac{p_s^{1-\frac{2\eta_t}{t}}}{(1-p_s)^{1-\frac{2\eta_t}{t}}}\right]^t$$

Notice that $\frac{p_s}{1-p_s} > 1$. Also, a direct application of Law of Large Numbers tells us that as $t \to \infty$, $\frac{\eta_t}{t} \to \begin{cases} p_s & \text{if} \quad \theta = \theta_H \\ 1 - p_s & \text{if} \quad \theta = \theta_L \end{cases}$ and $1 - 2\frac{\eta_t}{t} \to \begin{cases} < 0 & \text{if} \quad \theta = \theta_H \\ > 0 & \text{if} \quad \theta = \theta_L \end{cases}$. This, in turn, implies that $\rho_{1t} \to \begin{cases} 0 & \text{if} \quad \theta = \theta_H \\ \infty & \text{if} \quad \theta = \theta_L \end{cases}$.

2. Let η_{2t} denote the number of times $d^\tau = \overline{d}$ until period t. Given law of large numbers and borrowers equilibrium strategies, we can say that if $\theta = \theta_H$ then $\frac{\eta_{2t}}{t} \to \theta_H$. Otherwise, it is bounded above by θ_L. Then for any given $\{c^{\tau-1}\}_{\tau=0}^{t}$, $\prod_{\tau=1}^{t} \Pr\left(c^{t-1}|\theta = \theta_L\right) = 0$ if $\theta = \theta_H$ and $\prod_{\tau=1}^{t} \Pr\left(c^{t-1}|\theta = \theta_H\right) = 0$ if $\theta = \theta_L$. Hence, $\rho_{2t} \to \begin{cases} 0 & \text{if} \quad \theta = \theta_H \\ \infty & \text{if} \quad \theta = \theta_L \end{cases}$.

Combining these, we can say that $R_t \to \begin{cases} 1 & \text{if} \quad \theta = \theta_H \\ 0 & \text{if} \quad \theta = \theta_L \end{cases}$. Taking derivatives of ρ_{1t} and R_t with respect to p_s reveals that $\frac{d\rho_{1t}}{dp_s} \to \begin{cases} < 0 & \text{if} \quad \theta = \theta_H \\ > 0 & \text{if} \quad \theta = \theta_L \end{cases}$ and hence, $\frac{dR_t}{dp_s} \to \begin{cases} > 0 & \text{if} \quad \theta = \theta_H \\ < 0 & \text{if} \quad \theta = \theta_L \end{cases}$. ■

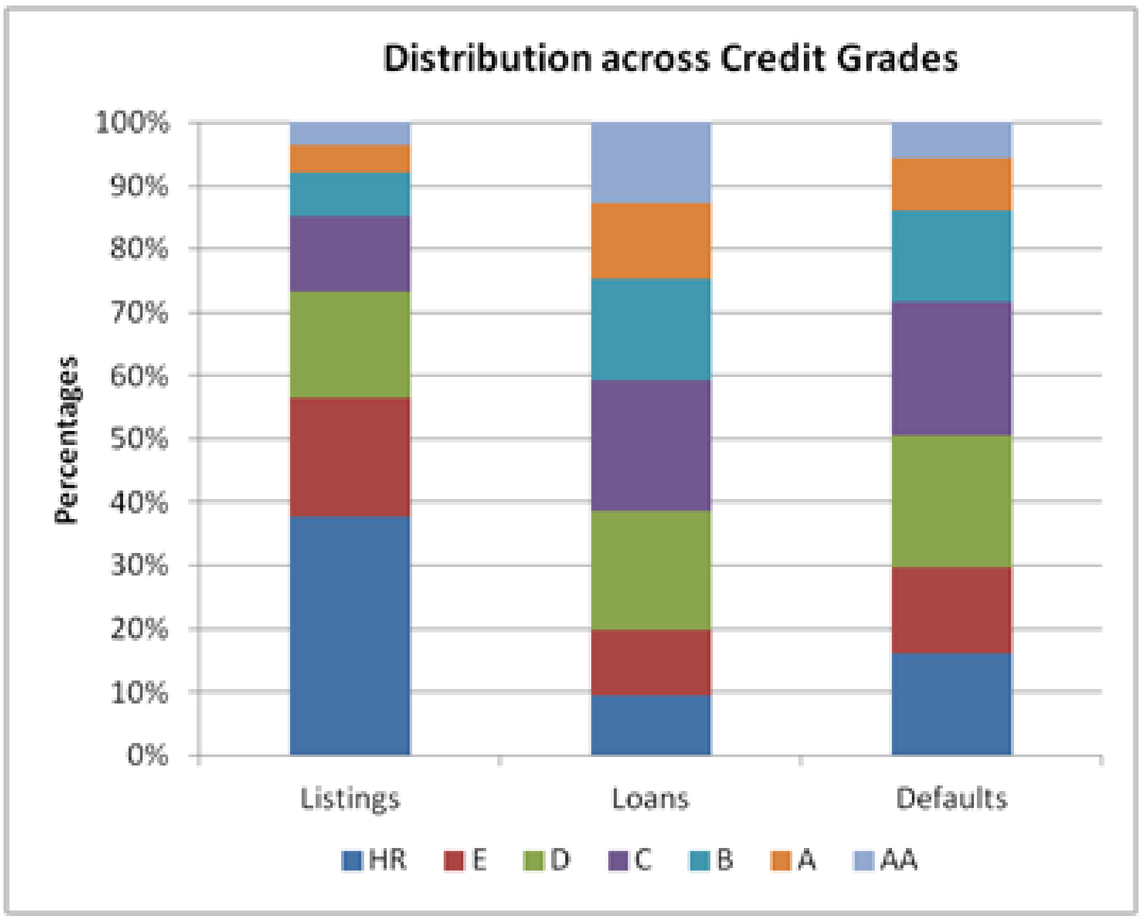
Proof of Proposition 9. Differentiating $\frac{d\rho_{1t}}{dp_s}$ with respect to p_s and taking limits reveals that $\frac{d^2\rho_{1t}}{dp_s^2} > 0$. Hence, ρ_t is convex in the informativeness of the signal, which is right meaning the convergence/divergence happens at a faster rate as signals become more informative. And $\frac{d^2R_t}{dp_s^2} \to \begin{cases} > 0 & \text{if} \quad \theta = \theta_H \\ < 0 & \text{if} \quad \theta = \theta_L \end{cases}$. ■

APPENDIX C.

FIGURES AND TABLES FOR CHAPTER 4

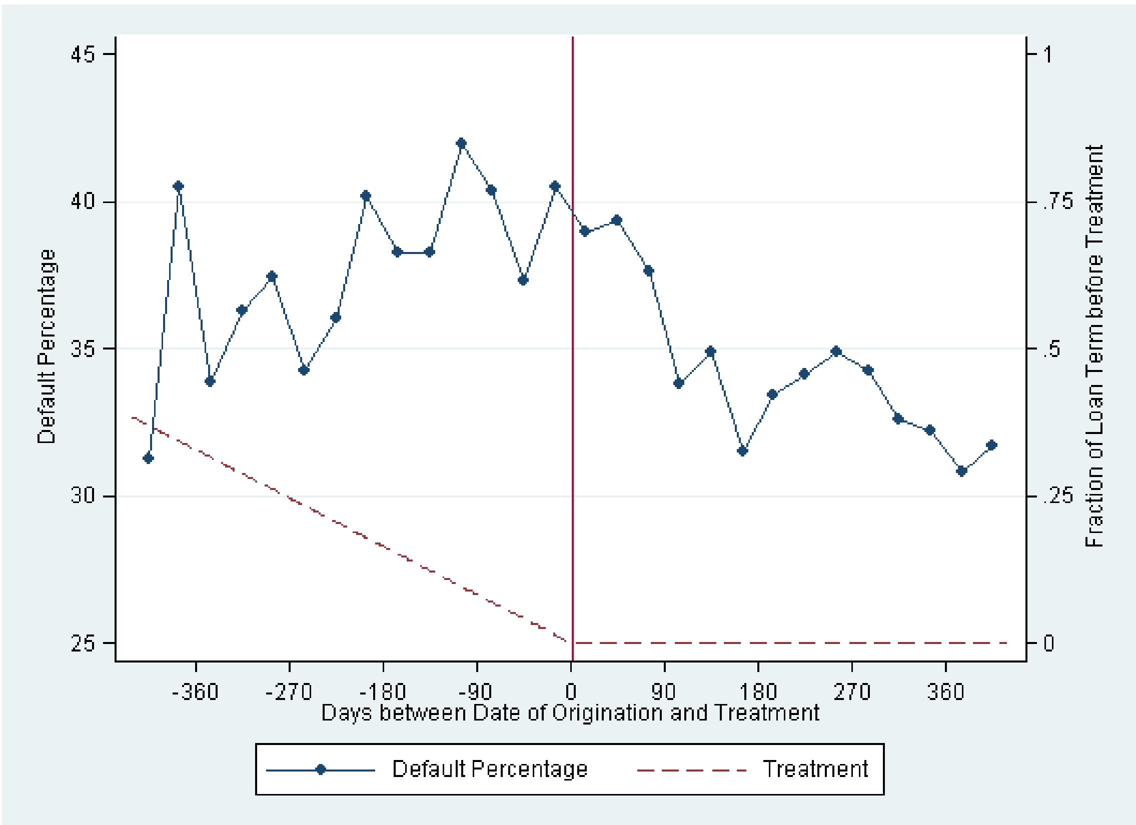
This appendix contains the figures and tables referenced in Chapter 4.

Figure C.1: Distribution of Listings, Loans and Defaults across the different credit grades



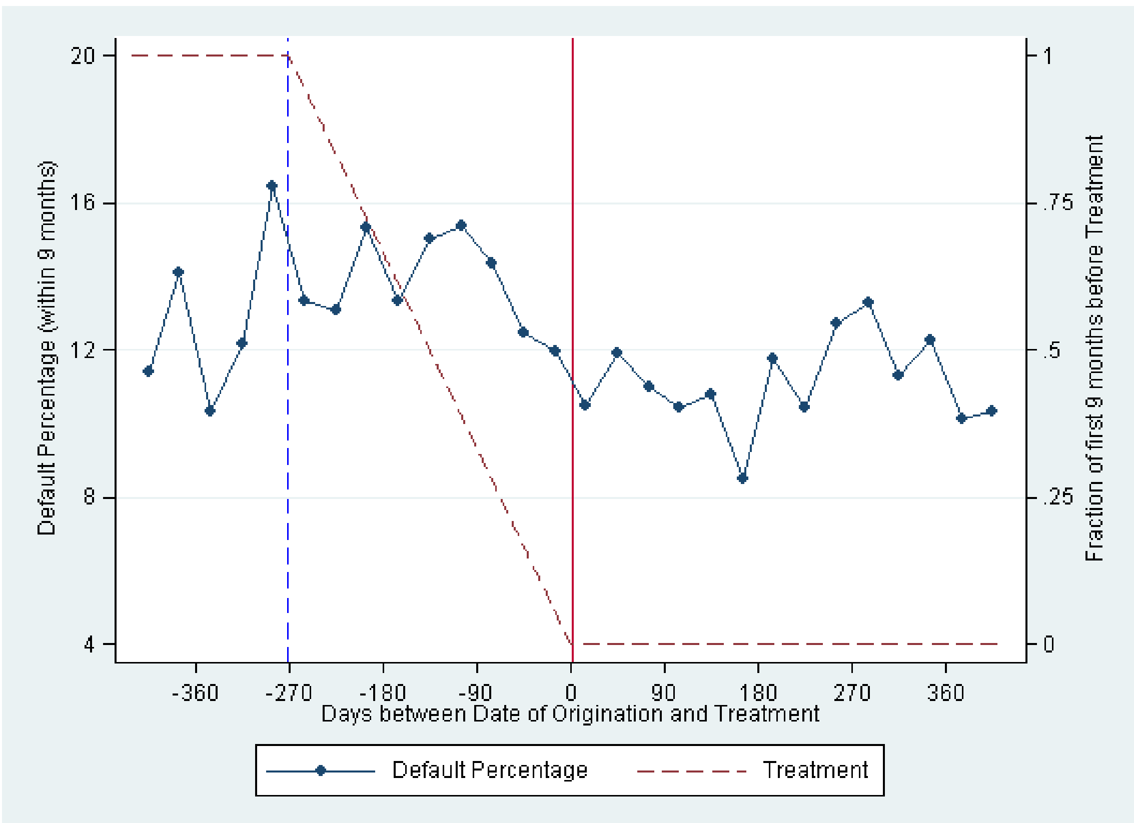
This breakdown is derived from the entire data sample used for analysis.

Figure C.2: Default percentage and variation in treatment



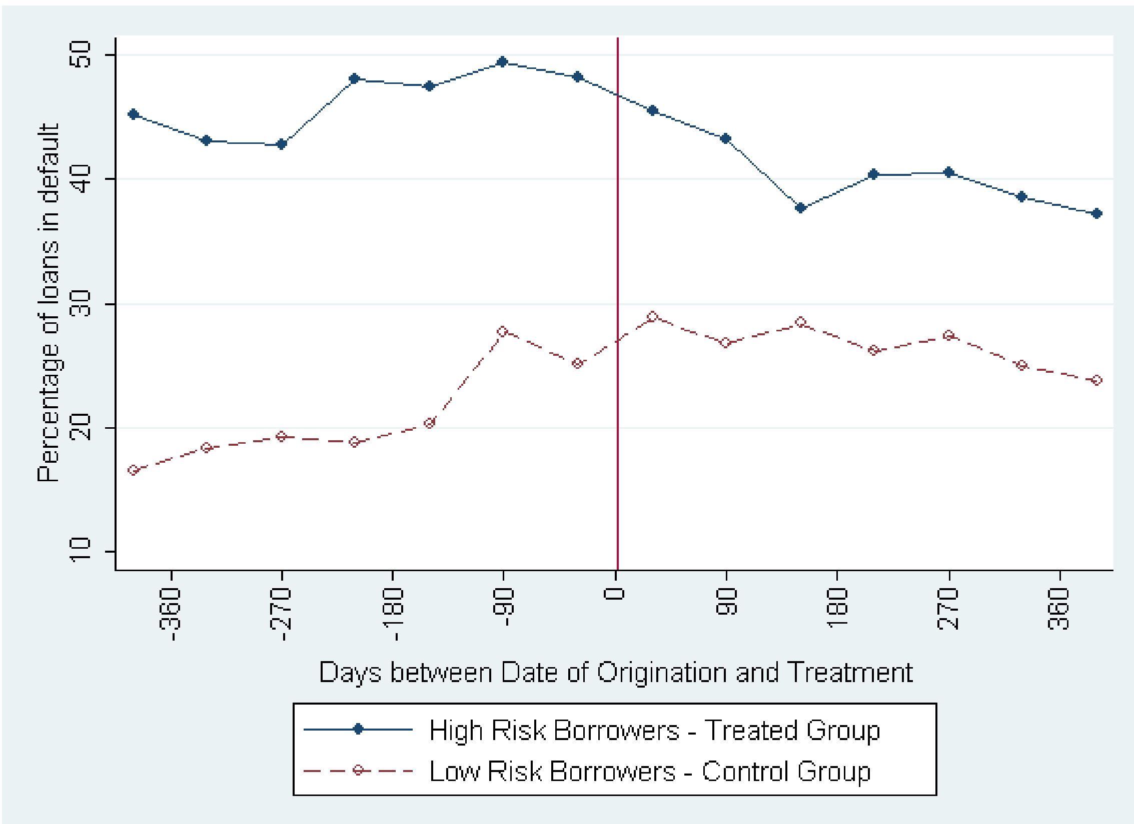
Data are divided into 30 day bins on either side of the treatment date and default rates are calculated inside each bin as the fraction of the loans in default.

Figure C.3: Default percentage within 9 months from origination and variation in treatment



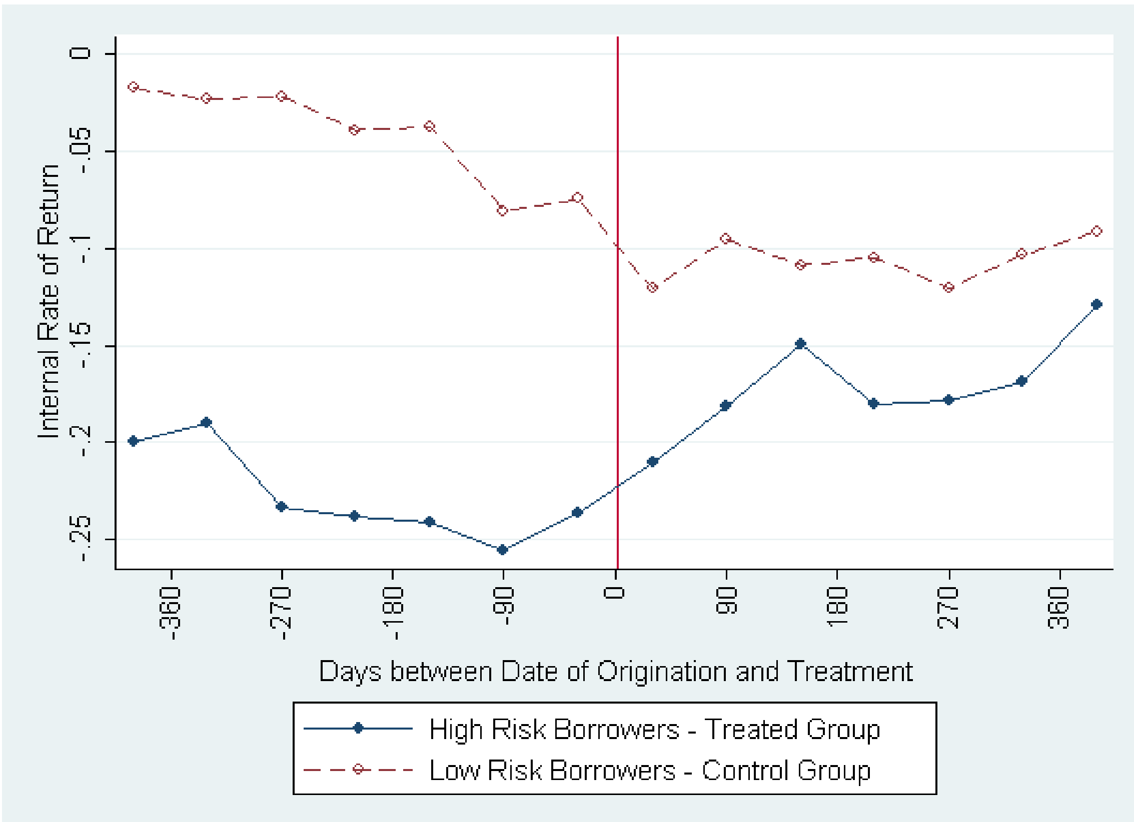
Data are divided into 30 day bins on either side of the treatment date and default rates are calculated inside each bin as the fraction of loans that default within 9 months from origination.

Figure C.4: Default Rates within 60 day bins – by borrower risk type



Data are divided into 60 day bins on either side of the treatment date. Default rates are calculated inside each bin separately for each risk type as the fraction of the particular risk type of loans in default.

Figure C.5: Internal Rate of Returns within 60 day bins – by borrower risk type



Data are divided into 60 day bins on either side of the treatment date. Internal rates of return are calculated inside each bin separately for each risk type as the mean internal rate of return of the particular risk type of loans.

Table C.1: Definitions of credit score bins and distribution of loans

Group	Credit Score Range	Credit Grades	Number of Loans	Percentage of Loans
1	520 - 539	HR	1,558	5.76
2	540 - 559		1,586	5.86
3	560 - 579	E	1,407	5.2
4	580 - 599		830	3.07
5	600 - 619	D	3,184	11.77
6	620 - 639		1,908	7.05
7	640 - 659	C	3,917	14.48
8	660 - 679		1,646	6.09
9	680 - 699	B	2,883	10.66
10	700 - 719		1,442	5.33
11	720 - 739	A	2,191	8.1
12	740 - 759		1,060	3.92
13	760 - 779	AA	1,790	6.62
14	780 - 799		721	2.67
15	800 and above		923	3.41
			27,046	100

This breakdown is derived from the entire data sample used for analysis.

Table C.2: Descriptive Statistics

	Before Treatment		After Treatment		
	High Risk[1]	Low Risk[2]	High Risk[1]	Low Risk[2]	Difference-in-Differences
BidCount	101.3524	180.6357	89.9406	232.285	63.06***
	(106.3736)	(161.4169)	(83.3858)	(175.9405)	(3.635)
BorrowerRate	0.209	0.1197	0.2239	0.1332	-0.00133
	(0.0521)	(0.0372)	(0.078)	(0.0502)	(0.00134)
Home Ownership (=1)	0.3389	0.6002	0.352	0.6298	0.0165
	(0.4734)	(0.4899)	(0.4776)	(0.4829)	(0.0122)
Image in listing (=1)	0.6471	0.6478	0.6558	0.6598	0.00323
	(0.4779)	(0.4777)	(0.4751)	(0.4738)	(0.0121)
Rating of Group (0 to 5)	0.7979	0.7421	0.3184	0.2236	-0.0390*
	(0.8391)	(1.0844)	(0.8254)	(0.7828)	(0.0235)
Default Percentage	0.4632	0.2183	0.4011	0.2660	0.110***
	(0.4987)	(0.4131)	(0.4901)	(0.4419)	(0.0115)
Internal Rate of Return	-0.2270	-0.0479	-0.1692	-0.1082	-0.118***
	(0.5079)	(0.3413)	(0.4919)	(0.3946)	(0.0107)
Observations	7599	4032	8437	6978	

[1] Borrowers with a credit score lower than 680 are defined as high risk.
[2] Borrowers with a credit score lower of 680 and more are defined as low risk.
Notes: Each cell contains the mean and standard deviation in parenthesis. The differences in differences were calculated from a regression similar to equation (2) with each of the variables as the outcome.
* Significant at the 10% level
** Significant at the 5% level
*** Significant at the 1% level

Table C.3: Time Series Approach

Panel A: Window Outcomes	1	2	3	4	5
	Default Rate within month n of origination				
Not Reported to TU (n = 6)	0.0160***	0.0176***	0.0209***	0.0337***	0.0679***
	(0.00373)	(0.00375)	(0.00370)	(0.00551)	(0.0113)
Default rate pre treatment			0.0817	0.1120	0.1660
Percentage effect			25.6%	30%	40.9%
Not Reported to TU (n = 9)	0.0188***	0.0192***	0.0303***	0.0477***	0.105***
	(0.00525)	(0.00527)	(0.00518)	(0.00739)	(0.0144)
Default rate pre treatment			0.1340	0.1778	0.2514
Percentage effect			22.6%	26.8%	41.8%
Not Reported to TU (n = 12)	0.0132**	0.0131*	0.0303***	0.0521***	0.111***
	(0.00670)	(0.00672)	(0.00657)	(0.00926)	(0.0175)
Default rate pre treatment			0.1781	0.2342	0.3197
Percentage effect			17%	22.2%	34.7%
Panel B: Overall outcomes	Default Rate				
Not Reported to TU	0.0317	0.0329	0.0948***		
	(0.0243)	(0.0244)	(0.0238)		
Default rate pre treatment			0.3783		
Percentage effect			25%		
	Internal Rate of Return				
Not Reported to TU	-0.00326	-0.00434	-0.0661***		
	(0.0234)	(0.0235)	(0.0233)		
IRR pre treatment			-0.1649		
Percentage effect			40%		
Observations	27046	27046	27046	16036	5381
Risk Types	All	All	All	< 680 credit score	< 600 credit score
Month of origin FE	No	Yes	Yes	Yes	Yes
Additional Controls	No	No	Yes	Yes	Yes

Notes: Each cell represents a separate regression. The unit of observation is a loan. The controls include number of bids on the loan, interest rate, dummy for homeownership of the borrower, dummy for an image on the listing, borrower's group rating and the lower bound of his credit score. Robust standard errors are reported in parenthesis.
* Significant at the 10% level
** Significant at the 5% level
*** Significant at the 1% level

Table C.4: Differences-in-differences Approach: Linear estimates

	1	2	Pre-treatment Rates
Panel A: Window Outcomes	**Default Rate within month n of origination**		
High Risk X PreTreatment (n = 6)	0.0489***	0.0685***	0.1120
	(0.0156)	(0.0223)	
Percentage effect	44%	61%	
High Risk X PreTreatment (n = 9)	0.0790***	0.0758***	0.1778
	(0.0251)	(0.0249)	
Percentage effect	43%	43%	
High Risk X PreTreatment (n = 12)	0.0973***	0.100***	0.2342
	(0.0326)	(0.0329)	
Percentage effect	42%	43%	
Panel B: Overall outcomes	**Default Rate**		
High Risk X PreTreatment	0.111***	0.0934***	0.4632
	(0.0312)	(0.0276)	
Percentage effect	24%	20%	
	Internal Rate of Return		
High Risk X PreTreatment	-0.131***	-0.126***	-0.2270
	(0.0373)	(0.0327)	
Percentage effect	58%	56%	
Observations	30	30	
Credit Range Fixed Effects	Yes	Yes	
Additional Controls	No	Yes	

Notes: Each cell represents a separate regression. The unit of observation is a credit range in the pre or post period. The controls include number of bids on the loan, interest rate, dummy for homeownership of the borrower, dummy for an image on the listing and the borrower's group rating. The percentage effect is calculated by using the default rates and internal rates of return of high risk borrowers in the pre treatment period. Robust standard errors are reported in parenthesis.
* Significant at the 10% level
** Significant at the 5% level
*** Significant at the 1% level

Table C.5: Differences-in-differences Approach: Log-Linear estimates

	1	2
Panel A: Window outcomes	**log(Default rate within month n of origination)**	
High Risk X PreTreatment (n = 6)	0.681***	0.904***
	(0.168)	(0.263)
High Risk X PreTreatment (n = 9)	0.891***	-0.0729
	(0.275)	(0.277)
High Risk X PreTreatment (n = 12)	0.812***	0.0717
	(0.213)	(0.150)
Panel B: Overall outcomes	**log(Default rate)**	
High Risk X PreTreatment	0.384***	0.0511
	(0.105)	(0.0919)
Observations	30	30
Credit Range Fixed Effects	Yes	Yes
Additional Controls	No	Yes

Notes: Each cell represents a separate regression. The unit of observation is a credit range in the pre or post period. The controls include number of bids on the loan, interest rate, dummy for home ownership of the borrower, dummy for an image on the listing and the borrower's group rating. Robust standard errors are reported in parenthesis.
* Significant at the 10% level
** Significant at the 5% level
*** Significant at the 1% level

Table C.6: Falsification tests - Placebo Treatment effects

	1	2	3	4	5	6
Panel A: True Treatment	Default rate within 6 months		Default rate within 9 months		Default rate overall	
High Risk X PreTreatment	0.0489***	0.0685***	0.0790***	0.0758***	0.111***	0.0934***
	(0.0156)	(0.0223)	(0.0251)	(0.0249)	(0.0312)	(0.0276)
Panel B: Placebo Treatments - Pre treatment data						
t - 300 days	-0.0199	-0.0283*	-0.0312	0.00208		
	(0.0179)	(0.0135)	(0.0439)	(0.0769)		
t - 330 days	-0.0163	-0.0166	-0.0423	0.0513		
	(0.0143)	(0.0114)	(0.0334)	(0.0316)		
t - 360 days	-0.0249	-0.0373***	-0.0262	-0.0298		
	(0.0151)	(0.00848)	(0.0380)	(0.0267)		
t - 390 days	-0.0372*	-0.0513*	-0.068	-0.0669*		
	(0.0185)	(0.0256)	(0.0453)	(0.0320)		
t - 420 days	-0.0465	-0.0189	-0.0753	-0.0170		
	(0.0284)	(0.0175)	(0.0517)	(0.0354)		
Panel C: Placebo Treatments - Post treatment data						
t + 180 days	-0.0139	-0.0144	-0.000832	0.00984	0.0291	-0.0450**
	(0.0112)	(0.0144)	(0.0135)	(0.0190)	(0.0230)	(0.0193)
t + 210 days	-0.00530	-0.0140	0.00454	0.00634	0.0217	-0.0177
	(0.0121)	(0.0135)	(0.0149)	(0.0168)	(0.0203)	(0.0196)
t + 240 days	-0.00106	0.0109	0.00597	0.0301	0.0313*	-0.00403
	(0.0113)	(0.0237)	(0.0132)	(0.0264)	(0.0174)	(0.0263)
t + 270 days	0.00602	0.0390**	0.0138	0.0545**	0.0359*	0.0387
	(0.0118)	(0.0172)	(0.0131)	(0.0210)	(0.0185)	(0.0298)
t + 300 days	0.00969	0.0285	0.0290*	0.0461	0.0326*	0.0251
	(0.0110)	(0.0191)	(0.0142)	(0.0289)	(0.0163)	(0.0373)
Observations	30	30	30	30	30	30
Credit Range Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Additional Controls	No	Yes	No	Yes	No	Yes

Notes: Each cell represents a separate regression. The unit of observation is a credit range in the placebo pre or post period. The controls include number of bids on the loan, interest rate, dummy for home ownership of the borrower, dummy for an image on the listing and the borrower's group rating. Robust standard errors are reported in parenthesis.

* Significant at the 10% level; ** Significant at the 5% level; *** Significant at the 1% level