Optimal Communication in Bank Lending Decisions

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Abstract

I study the optimal design of compensation contracts and information systems that motivate loan officers to provide high effort and truthful communication of borrowers' soft information. I explore how a bank can balance these competing objectives in equilibrium. My findings suggest that if the bank seeks to incentivize both effort and truthful communication, it may design a positively biased information system and compensate loan officers even if a loan application is ultimately rejected. When the cost of motivating effort increases, the bank may opt for a less informative information system and shift to a hard information regime that prioritizes perfect revelation of states while disregarding soft information communication. Interestingly, the loan officer may prefer a perfect information system if she is in charge of the information design process.

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Chapter 1

Introduction

Bank lending decisions involve the consideration of two types of information: soft information and hard information. Soft information pertains to the borrower's subjective characteristics that can only be acquired through personal interaction with the borrower, such as their managerial skills, motivation, and beliefs. This information is referred to as the borrower's "type." In contrast, hard information pertains to objective data about the borrower's financials, industry and macroeconomic conditions and trends, which can be obtained from more objective sources[1]. This information is referred to as the borrower's "state." Both types of information are crucial in determining the future cash flows from the project that is being financed, but they are dispersed throughout the organization. Loan officers who interact with and monitor the borrower obtain the soft information about the borrower's type, while the hard information is obtained by bank headquarters. To make the final loan decision, the centralized loan committee at bank headquarters processes both the soft and hard information obtained from various sources.

What information exchanges between loan officers and bank loan committees would we

[1]Industry conditions and trends can be obtained from government agencies, trade associations, market research firms, financial statements, and news articles, including market size and growth rates, market share and competition, regulatory requirements and constraints. Macroeconomic conditions and trends can be obtained from government agencies, central banks, economic research firms, and financial news outlets, including macroeconomic data and policy decisions.

expect to see given that both agents communicate strategically? Should the communication be one sided with either the loan committee withholds information about the state from the loan officer or the loan committee ignores loan officers' reports about client types? Or should the loan committee selectively disclose information about the state to ensure the loan officer honestly reports the client types? Complicating these questions are a moral hazard issue and the lack of credibility for loan officer to communicate soft information. In our setting, the information that loan officers obtain is obtained in two stages. The first stage consists of a preliminary screening by loan officers of the pool of potential borrowers[2]. The greater the effort supplied by loan officers at this stage the greater is the probability that low quality borrowers are screened out at the first stage so that the borrower who shows up at the second stage has a higher probability of being high quality. The borrower's type (High or Low) is privately revealed to the loan officer at this second stage without any commitment, as borrower's type is naturally soft information which is "hard to quantify, verify, and communicate through normal transmission channels of a banking organization" (Berger and Udell, 2002). The screening effort supplied by loan officers is unobservable and privately costly. The bank designs and commits to a compensation contract and information system for loan officers that provides effort incentives and also affects the loan officer's communication strategy with the loan committee. Does the need to motivate high effort interfere with the need for communication of the borrower's type? What is the nature of this tradeoff?

The above questions are addressed in a stylized model where all variables of interest are binary. If funded, there are only two possible outcomes; The project could either succeed or fail. The state could be either G (good) or B (bad), and the borrower could be either type H (high) or type L (low). Loan officers could either work or shirk at the stage one screening of potential borrowers. We assume that if the state is B, the project will fail with probability one, regardless of borrower type. If the state is G, then both types of

[2]This preliminary screening is regarded as a primary role of loan officers in banks (eg. Freixas and Rochet, 2008).

borrowers have positive probabilities of making the project succeed, but a type H borrower has a higher probability of project success. The expected net present value of the project is positive if and only if the borrower is of type H and the state is G. Thus, in a first best world, the project would be funded only if these conditions hold.

I model the reporting system design as a persuasion game in which the bank persuades the loan officer to disclosue information about a borrower's type, while formulating the disclosure strategy of the loan officer is formed as a cheap talk game à la Crawford and Sobel (1982). I adopt following steps to characterize the equilibrium of this game. First, I solve for the optimal information system for any given contract and given effort level, conditional on whether the loan officer is communicating with the bank honestly. I then solve for the optimal contract under different information regimes inducing corresponding level of efforts given the optimal information system determined in step one. Lastly, I compare the outcome under two different information regimes to determine the equilibrium outcome.

I obtain several important results. First, if the bank wants its loan officers to exert effort at the stage one screening of potential borrowers and simultaneously communicate the borrower's type honestly to the loan committee, then optimally the information provided to loan officers about the state may not be fully revealing. The communication should be such that loan officers can make a perfect inference when the state is B, but are unable to make a perfect inference when the state is G. The intuition for this result is the following. Since a type L borrower has negative NPV in both states, the loan committee never funds a borrower that is known to be of type L. Additionally, I show that in order to motivate high effort, the bank must pay the loan office handsomely if the project is funded and it succeeds and pay the loan officer the lowest amount feasible if the project is funded but it fails. The loan officer is compensated some intermediate amount when the project is not funded. Then, if the loan officer knows that the state is G and that the borrower is type L, honest revelation of the borrower's type will result in the loan not being funded in which case the loan officer receives only the intermediate amount of compensation. However, if the type L borrower is misrepresented as a type H borrower the loan application will be approved by the loan committee, resulting in a small but positive probability of project success and therefore a small but positive probability of the loan officer receiving the handsome compensation. Thus, perfect information about the state inhibits honest communication of the borrower's type.

The above results highlight potential determinants on when banks would prefer communication from loan officers and when banks would ignore them. Under hard information regime, it is always optimal for the bank to establish a fully informative reporting system, and pay nothing when the loan is not being funded, as it does not need to persuade the loan officer to disclose his private information honestly. Therefore, whether the bank should use loan officer's soft information in loan approval is determined by comparing the investment inefficiency in two regimes and the cost of inducing loan officer's truthful communications.

I show that a crucial determinant of the bank's choice of information system is how costly it is for the bank to motivate unobservable screening effort from the loan officer, either because the private cost for the loan officer is high or her effort could not significantly improve the average quality of the borrowers. Suppose the effort is costless or does not affect the average quality of the borrowers, the bank does not need to compensate the loan officer for his effort, and the loan officer would have no incentive to lie about the borrower's type ex-post. As the cost of motivating effort grows, the bank has to increase the payment to the loan officer when the loan is approved and performs, which induces the loan officer to lie when the expected probability of good state is sufficiently high. To balance this incentive, the bank would first increase the payment to the loan officer when the loan is rejected and then move away from the perfect information system by reducing the informativeness of good news, leading to over-investment from ex-ante perspective. Hence, the more costly to motivate unobserving effort, the more costly for the bank to induce truthful communication from the loan officer because of both higher compensation after rejecting a loan application and the frequency of over-investment under bad state. When the cost of motivating unobserving effort is sufficiently high, the bank will find it too costly to induce honest communication from the loan officer; thus it overlooks soft information about the borrower's type and relies only on hard information from the information system, whereas the inefficiency comes from investing to low type borrower under good state whose cost is fixed. I also find that both a low average quality of borrowers or an optimistic prior about the economy would lead to a soft information regime, even if it means not fully revealing the state of economy, as both factors make overinvestment less costly under the soft information regime.

In the main setting, I assume the bank headquarter has the authority to design the information system. I then examine a simple extension when the loan officer has the authority to design the information system. Interestingly, I establish that the loan officer would always prefer a perfect information system, given that the compensation to the loan officer if the loan application is rejected is not too high. Under a fully informative system, a low compensation when the loan is rejected implies the loan officer would lie about the borrower's type when the state is good. Compared to a positive biased system where the loan officer is honest about the borrower's type, his expected compensation is higher under a fully informative system as he would always get paid under the bad state as the loan would be rejected regardless of the borrower's type. Therefore, compared to the case where the bank headquarter has the authority over information design, it would be more costly for the bank to elicit truthful communication. The bank would prefer a hard information regime more often if it defers information design to the loan officer.

I also examine the robustness of some model assumptions. I show that loan officers communicate their information before the loan committee communicates its information about the economy does not affect our results, as the bank can always obtain the same payoff with a mechanism switching the sequence of information transmission. However, ex-ante effort undertaken before the information about economy is revealed is important, as the optimal information system is always fully revealing with effort undertaken after the information about economy is known.

Although my paper focuses on a banking setting, the fundamental idea of this paper could be carried to broader principal-agent settings. Rather than being the loan officer, the agent could be any risk taker who needs to exert effort ex-ante to increase firm value and truthfully report soft and unverifiable private information simultaneously. Examples of such agents could include traders in financial institutions and managers or CEOs in non-financial firms. As long as the information system aims to identify and eliminate downside risk, my results would potentially apply.

The remaining chapters of this dissertation proceeds as follows. Chapter 2 discusses related literature and our contribution. Chapter 3 describes the main economic setting of this paper. Chapter 4 presents the main results of this dissertation, including the optimal information system and compensation contract under the hard and soft information regimes, and the bank's optimal choice between hard and soft information regimes. Chapter 5 discusses how our results would change if certain assumptions were altered and the empirical implications of analytical results. Chapter 6 concludes this dissertation. All proofs are deferred to the Appendix.

Chapter 2

Related Literature

My study contributes to the literature investigating the internal lending processes of the banking sector. To my knowledge, this is the first paper that explores the interplay between loan officers' compensation, the design of banks' internal reporting system, and the revelation of interim private information by loan officers. Stein (2002) analyzes how organizational design affects information production related to investment projects and capital allocation towards such projects. He argues that decentralization is the better approach when information about the project cannot be credibly transmitted[1]. In a banking context, his findings offer an explanation for the decline in small-business lending following consolidation in the banking industry[2]. Although both papers examine the incentives of information transmission, Stein (2002) focuses more on the role of organizational structure, while my paper places greater emphasis on the role of the reporting system.

Heider and Inderst (2012) investigate the relationship between loan officer compensation and private information revelation by the loan officer. In their paper, the loan officer needs to be simultaneously incentivized to prospect new borrowers and reveal information about their quality. Both studies demonstrate that banks are willing to tolerate ex-ante

[1] In other words, the information about the project is ”soft”.

[2] For empirical evidence on this issue, see Berger et al. (2005) and Liberti and Mian (2009).

losses on some loans as it mitigates their internal agency problems concerning loan officers, who face a multi-tasking problem during the screening process of borrowers (balancing effort and interim information disclosure)[3]. Although we share a common interest in the multi-tasking problem faced by loan officers with regards to two types of information, they do not consider the endogeneity of public information, which is a primary focus of our paper.

In this paper, I present a multi-tasking model that incorporates a moral-hazard problem (unobservable screening effort) and a soft information revelation problem. The modeling and solution strategy are similar to previous studies like Dewatripont and Tirole (1999), Heider and Inderst (2012), and Levitt and Snyder (1997). However, my paper contributes a new insight: higher incentives to screen borrowers can increase the cost of obtaining soft information from loan officers, leading to an endogenous bias toward loan approval. To address this issue, the bank adjusts the loan officer's compensation and information system, at the cost of additional rents to the loan officer and inefficiencies during the loan approval process. In that sense, my paper also relates to the literature examining the consequences of pre-decision information in moral hazard problems[4]. Most early studies focus on single task model with exogenous public information, with the exception of Göx and Michaeli (2022). Both my paper and theirs feature unobservable effort, but I also consider the role of information in promoting internal communication.

This paper is related to the literature on Bayesian persuasion and its application in accounting[5] as I utilize the Bayesian Persuasion framework to characterize the optimal

[3]Other papers have identified different sources of excessive lending, including manager's reputation concerns (Rajan 1994) and the deterioration of loan officer's ability to screen out bad loans over time (Berger and Udell 2004).

[4]Early papers include Baiman and Sivaramakrishnan (1991), Baker (1992), Bushman, Indjejikian and Penno (2000), Penno (1984), where the accounting application focuses on the desirability of participative budgeting.

[5]Kamenica and Gentzkow (2011) formalize the idea that a sender commits to an information transmission strategy to influence the receiver's action. Accounting applications include the formalization of designing accounting system with information acquisition of a receiver (Huang (2016), Gregor and Michaeli (2020)), agency problems (Göx and Michaeli (2019)), multiple receivers (Michaeli (2017)), ex-post disclosure of private information (Friedman, Hughes, and Michaeli (2020)).

information system. Unlike existing literature, the paper considers a setting with multi-dimensional states of the world where the sender (bank) designs the reporting system on one dimension to incentivize the receiver (loan officer) to share their private information on the other dimension. Jain (2020) studies a sender-receiver game with a two-dimensional state of world such that the sender commits to a signal on one dimension and engages in cheap talks on the other, while the receiver, rather than the sender, engages in cheap talks in my setting. The bias for the sender is exogenous in her setting, while the bias arises endogenously for the loan officer in ours due to the need to incentivize unobservable effort. Friedman, Hughes, and Michaeli (2020) study the optimal reporting system with subsequent discretionary disclosure by firms facing thresholds on investors' beliefs. Unlike our paper, the state of the world has only one dimension in their paper, and the ex-post disclosure in their paper is discretionary but verifiable. Michaeli (2017) showed that the manager would gather more precise information if she could disseminate her information to a selective set of users when incentive misalignment between users and her is sufficiently large. Unlike her study, my paper focuses on how ex-post strategic communication affects the incentive of a bank to gather information, and the incentive misalignment is endogenized through multi-tasking.

Finally, this paper also contributes to the literature on information transmission within the organization by demonstrating that information design can facilitate communication. Such literature typically employs a cheap-talk framework to formalize communication, which is also featured in my paper. One of the key findings from this literature is that weaker corporate governance or less intervention from the principal may enhance communication and improve the principal's payoff (Adams and Ferreira 2007; Banerjee and Szydlowski 2020.). This finding is analogous to my own, which suggests that the bank would implement a positively biased accounting system, leading to excessive lending.

Chapter 3

Model

I study a model with five dates, $t \in \{0, 1, 2, 3, 4\}$, where the bank is facing a multi-task agency problem with its loan officer: the loan officer needs to be motivated to simultaneously improve the probability to identify a good customer and reveal soft information about the customer to the bank for approval decisions.

3.1 Borrower

A potential new borrower has a project whose successful probability is jointly determined by the borrower's type and underlying economic state if the loan is approved. The loan size is assumed to be $k > 0$. The repayments to the bank in case of success and failure, $y \in \{R^s, R^f\}$, which is assumed as given, are independent of both borrower's type and underlying economic state. Without affecting our results qualitatively, we set $R^f = 0$ and $R^s = R$, so a failed project would yield zero to the bank.

There are two types of borrower, $\theta \in \{L, H\}$, and two underlying states, $\eta \in \{G, B\}$. If the borrower is a H type, the project has a probability $p_{GH} = p_G$ of success under state G, and probability $p_{BH} = 0$ under state B at $t = 4$. If the borrower is a L type, the probability of success is $p_{GL} = zp_G$ under state G with $z \in (0, 1)$, and $p_{BL} = zp_B = 0$ under state B

at $t = 4$. The prior probability that G state occurs is p_0. We assume that the borrower's project has positive net present value (NPV) if and only if the state is G and the borrower's type is H. Mathematically, these assumptions are specified as $zp_G R < k < p_G R$.

3.2 Moral Hazard

A loan officer lacking wealth is working for a bank. He has zero reservation utility and is protected by limited liability. The loan officer could exert a non-observable effort e at the cost of $c(e)$ to improve the probability of encountering an H-type borrower. The effort e represents the loan officer's deployment (or investment on specific human capital) of his specialized knowledge of markets or industries in discovering new borrowers, which improves the effectiveness of initial screening on potential borrowers[1]. To simplify the problem, we consider the binary case such that $e \in \{0, 1\}$, with $c(0) = 0$ and $c(1) = c$. If the loan officer takes $e = 1$, the probability of encountering an H-type borrower is q. If the loan officer takes $e = 0$, *i.e.*, shirks, the probability of encountering an H-type borrower becomes $q - \Delta$.

3.3 Information

The bank could design a public information system about η, which produces a noisy signal r about the actual state realization and is observed by both the loan officer and the bank. The signal r induces an interim belief $\mu_r = Pr(G|r)$. The design of the reporting system is equivalent to selecting a probability distribution of interim beliefs from a set of report realizations as long as the Bayes plausibility constraint is satisfied.

[1]There are two alternative interpretations on effort e which are consistent with the idea of improving borrowers' quality. The first interpretation builds on the loan prospecting setting studied by Heider and Inderst (2012), where the loan officer exerts efforts to establish linkages with high quality borrowers to deter competition from other lenders. The second interpretation builds on Diamond (1991) where the loan officer monitors borrowers before loan origination to reduce the private benefits that borrowers can enjoy by shirking (Holmström and Tirole, 1997).

The borrower's type θ is the loan officer's private information and is not available to the board. After seeing r, the loan officer would send a message m to the board regarding his type after learning θ.

3.4 Contracting

After the realization of r and the loan officer's message m, the bank would decide whether to accept or decline the loan application[2]. Denote the set of report realizations as $\mathbb{R}$ and the message realizations as $\mathbb{M}$. The set of all possible combinations of information that the bank faces is $\Omega = \mathbb{R} \times \mathbb{M}$. The set of all $(r, m) \in \Omega$ for which the bank accepts the loan application is denoted by A.

The contract would specify compensation for the loan officer. For simplicity, we focus on contracts such that the payment to the loan officer is 0 if a loan is approved and the borrower defaults, a bonus w_s if a loan is approved and the borrower successes, and a fixed payment w_0 if the bank rejects a loan application and no loan is made. We make two additional assumptions. First, we assume that the loan officer is protected by limited liability so that both w_s and w_0 are non-negative. Second, we assume that both R and k are sufficiently large, so we always have $w_s < R$ and $w_0 < k$ in equilibrium.

3.5 Timeline

I now describe the timeline of the game. At $t = 0$, the bank simultaneously offers the loan officer a contract specifying a compensation scheme (w_s, w_0) and designs a reporting system $\mathbb{R}$. The loan officer will exert effort e at $t = 1$ to improve the quality of potential borrowers if he accepts the offer. When the new loan opportunity is generated at $t = 2$, the reporting system will generate a report realization r at $t = 2$, and the loan officer will learn

[2] One way to interpret this assumption is that bank headquarters must evaluate multiple projects simultaneously and only approve those sufficiently profitable projects, thus k could be interpreted as the hurdle rate of a bank.

the borrower's type θ. After seeing r, the loan officer would communicate the borrower's type to the bank at $t = 3$, and the bank decides whether or not to approve the loan. If the loan is approved, the borrower repays y depending on whether the project is successful, and the loan officer receives his payment correspondingly. All parties are assumed to be risk neutral, and there is no discount on future cash flows.

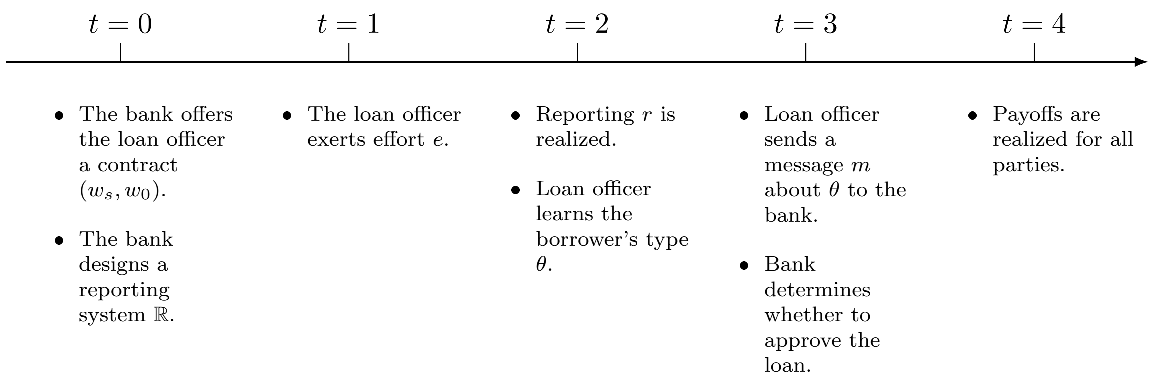
3.6 Equilibrium Characterization

As other models featuring cheap talk, I start with the scenario where there is no effective communication and the bank would only use hard information to make loan approval decisions. In this babbling case, I characterize the equilibrium through three steps. First, I assume a given level of effort from the loan officer and determine the bank's optimal information system for a specific contract (w_s, w_0). Next, I derive the incentive contract given the effort level and the optimal information system obtained in step 1. Finally, I characterize the equilibrium by identifying the optimal level of effort the bank wants to induce.

I then move on to the case where the loan officer's communication would impact the bank's loan approval decisions. Unlike conventional principle agent problems, the Revelation Principle could no longer apply to our setting as the bank does not specify the approval rules in contracts with loan officers. However, using an extended version of revelation principle, I establish that it is sufficient to consider the class of equilibrium in which a loan officer with a high type borrower is honest while a loan officer with a low type borrower may lie. Moreover, any equilibrium wage contract and information system which could sustain an equilibrium within this class could also sustain an equilibrium such that the loan officer truthfully reveals his soft information regardless of reporting realizations. As truth-telling equilibrium maximizes the bank's payoff, I restrict my interest to contracts and information system in which the loan officer truthfully reveals his soft information regardless of report realizations. Similar to the babbling case, I follow the same three steps to characterize the equilibrium, except taking truth-telling constraints into account. I then determine the optimal information scheme for lending by comparing the outcome with communication to the babbling case.

Figure 1 summarizes the timeline of events in this model if the loan officer accepts the contract.

Figure 3.1: Timeline



Chapter 4

Main Results

4.1 Benchmark: First Best Allocation

I start from the case where the loan approval decision is efficient, and there is no information asymmetry besides unobserved effort level, *i.e.*, the bank knows both η and θ and approves the loan if and only if $\eta = G$ and $\theta = H$. As the bank does not need to facilitate information transmission from the loan officer, the only objective of the incentive scheme is to induce the loan officer to exert effort, which becomes a canonical principal-agent problem.

It is straightforward that the optimal contract to induce effort $e = 0$ is to offer $w_s = w_0 = 0$, as positive payments are not necessary to compensate the loan officer's effort. We now exclusively focus on the contract inducing effort $e = 1$. As the loan approval rule is pre-determined, the expected NPV from the project is fixed when the loan officer exerts $e = 1$, which is equal to $qp_0(p_G R - k)$. Thus, the optimal contract minimizes compensation cost subject to incentive compatibility constraints and non-negative constraints for wage payments. Lemma 1 summarizes the optimal contract.

Lemma 1. *Under the first-best loan approval rule with perfect information, if the bank wants to induce the loan officer to undertake effort* $e = 1$*, the optimal compensation is* $w_s = \frac{c}{\Delta p_0 p_G}$

and $w_0 = 0$.

Lemma 1 suggests that the bank's ex-ante expected payoff π_P if the loan officer undertakes $e = 1$ would be equal to $qp_0(p_G R - k) - q\frac{c}{\Delta}$. To make effort level $e = 1$ optimal, we must have

$$p_0(p_G R - k) - q\frac{c}{\Delta} \geq (q - \Delta)p_0(p_G R - k) \quad (4.1)$$

which implies

$$c \leq \frac{\Delta^2 p_0(p_G R - k)}{q} = \bar{c}. \quad (4.2)$$

From now on, I assume the loan officer's cost to undertake $e = 1$, c, satisfies (4.2).

The benchmark cases indicates that the existence of soft information that cannot be solidified would complicate the loan officer's incentive problem. In order to motivate the loan officer to exert effort, the compensation scheme that minimizes costs sets the compensation to 0 if the loan is not approved. However, this creates a situation in which the loan officer strictly prefer the bank to approve the loan regardless its NPV. As a result, the loan officer has incentives to misrepresent his soft information during the loan approval process.

4.2 Hard Information Lending

Let us now consider the scenario where the bank approves loan applications based solely on hard information obtained from the information system. Since the bank ignores any information transmission from the loan officer, the incentive scheme's sole objective is to motivate the loan officer to exert efforts.

I start from the case where the bank wants to induce effort $e = 0$. I first show that regardless of the information system chosen by the bank, the optimal contract to induce effort $e = 0$ is to offer $w_s = w_0 = 0$ since any positive payments would reduce the bank's payoff. As there are no payments to the loan officer, the bank selects an information system to maximize its expected payoff without additional constraints. Thus it selects the most informative system, *i.e.*, the information system perfectly reveals state η. The bank would approve the loan if and only if: (1) $\eta = G$; (2)$[q - \Delta + (1 - q + \Delta)z]p_G R \geq k$.

I now proceed to characterize the optimal contract inducing effort $e = 1$. I first identify that to induce effort $e = 1$, at least one report realization r must exist so that the bank would approve the loan. I prove this claim by contradiction. Suppose the opposite case is true, then the bank would always reject the loan application under any r even if the loan officer exerts $e = 1$, implying the loan officer's payoff is equal to $w_0 - c$ if she exerts $e = 1$. In contrast, if the loan officer exerts $e = 0$, her payoff is w_0 which is strictly higher than $w_0 - c$. Thus, the contract cannot induce the loan officer to exert $e = 1$ if the bank always rejects the loan application.

Next I characterize the optimal information system given any contract which induces $e = 1$.

Proposition 1. *Under hard information lending, the optimal information system is fully informative given any contract inducing $e = 1$.*

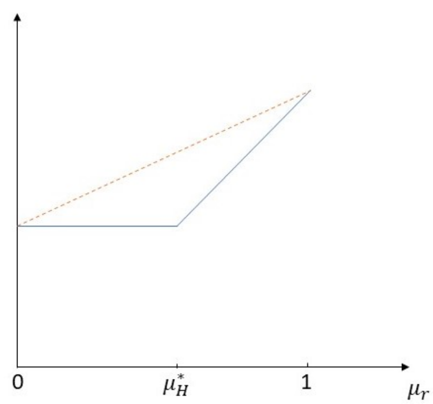


Figure 4.1: Optimal information system with only hard information. The solid line is the bank's expected payoff conditional on belief μ_r. The dashed line represents the concavification of the bank's expected payoff.

As shown by figure 2, the bank's payoff function is convex in the absence of incentive compatibility and truth-telling constraints. Thus, as long as these constraints are not violated, the bank would incur a loss if the reporting system is not fully informative. In the case of the hard information regime, the only relevant constraint is the incentive compatibility constraint, which aims to motivate loan officers to exert efforts.

Next, I show that the loan officer's expected gain from undertaking $e = 1$ is weakly higher under a perfect reporting system. Intuitively, a loan officer benefits from his efforts when the loan is approved and the state is good. If a report realization r with $\mu_r \in (0, 1)$ leads to loan rejection, the loan officer's expected gain from undertaking $e = 1$ will be higher under a perfect reporting system as it leads to a positive probability of loan approval. If a report realization r with $\mu_r \in (0, 1)$ leads to loan approval, the loan officer's expected gain from undertaking $e = 1$ will be the same under a perfect reporting system as from ex-ante perspective, the probability of loan approval under good state will be the same. Therefore, I conclude that regardless of contract payments, the optimal information system to induce $e = 1$ is fully informative.

Now I proceed to characterize the optimal contract under hard information lending. As the reporting rule is unique and fully informative, the expected NPV from the project is fixed when the loan officer exerts $e = 1$, which is equal to $[q+(1-q)z](p_G R-k)$. Thus, the optimal contract would minimize the compensation cost subject to incentive compatibility constraints and non-negative constraints for wage payments. Proposition 2 summarizes the optimal contract.

Proposition 2. *Under hard information lending, if the bank wants to induce the loan officer to undertake effort $e = 1$, the optimal compensation is $w_s = \frac{c}{\Delta p_0 p_G(1-z)}$ and $w_0 = \max\{0, k - [q + (1 - q)z]p_G(R - \frac{c}{\Delta p_0 p_G(1-z)})\}$.*

Under hard information lending, the loan officer would always receive w_0 under state B. Her compensation under state G is determined by w_s and the probability that loan repayment is successful. Hence, w_0 does not affect the incentive compatibility constraint, which makes the loan officer optimally undertake $e = 1$, and we could explicitly characterize equilibrium w_s using the incentive compatibility constraint. The role of w_0 is to ensure that the bank approves the loan under state G.

Our next proposition characterizes the optimal effort level the bank induces under hard information lending.

Proposition 3. *Under hard information lending, the bank optimally induces the loan officer to exert $e = 1$ if $[q + (1 - q)z]p_G(R - \frac{c}{\Delta p_0 p_G(1-z)}) \geq \max\{k, [q - \Delta + (1 - q + \Delta)z]p_G R\}$, and induces the loan officer to exert $e = 0$ otherwise.*

Proposition 3 implies that in the case of hard information lending, the wage payment when the loan is not approved must be zero, regardless of the equilibrium effort level. This means that a positive wage payment is only possible when the loan is approved and performs. The reason behind this is that if the bank needs to offer a positive wage payment to induce higher level of effort, it would be optimal for the bank to let the loan officer shirk instead.

4.3 Soft Information Lending

In this section, I analyze the equilibrium choice of compensation and information system under soft information lending. In this case, the loan approval decision is influenced not only by the information generated from the chosen information system, but also by the borrower's type information that the loan officer can only communicate without credibility. Therefore, in addition to inducing pre-screening effort from the loan officer, the compensation scheme and information system design must also facilitate truthful communication of the borrower's type by the loan officer.

As hard information lending, I start from the case where the bank wants to induce effort $e = 0$. Again, given any information system, the optimal contract to induce $e = 0$ would offer $w_s = w_0 = 0$, as positive payments only reduce the bank's payoff. Since there are no additional constraints on the bank's information system design, it would always choose the most informative one, which perfectly reveals state η.

Next, I determine the optimal combination of an incentive contract and an information system that induces effort $e = 1$. Since the bank does not contract on loan approval rules, the conventional Revelation Principle could no longer be applied. However, as the type space for borrower is binary, an extended version of Revelation Principle from Bester and Strausz (2001) can still be applied to refine the equilibrium and each player's strategies. First, given binary borrowers' types, it is sufficient to consider a binary message space $\mathbb{M} = \{h, l\}$. This is a direct result of Proposition 1 from Bester and Strausz (2001), which states that with finite types, the agent's message space is finite and its dimensionality is not higher than the dimensionality of agent's type space. Second, I can further restrict my interest to the case where there is at least one report realization r such that leads the bank to grant the loan after seeing $m = h$ message but rejects the loan after seeing $m = l$ type. To understand why this is necessary, assume the opposite case. In that scenario, the bank's loan approval decision would not depend on the communication from the loan officer. Consequently, the bank's payoff could be replicated with the same contract and information system used in hard information lending. This replication would yield no higher payoff than the optimal contract and information system obtained when the bank solely relies on hard information.

Definition 1. *Given any wage contract $\{w_s, w_0\}$, a report r is **informative** if after seeing r, the bank approves loan application after seeing $m = h$ and rejects loan application after seeing $m = l$.*

My first lemma characterizes the feasible communication strategies of loan officer under any *informative* report.

Lemma 2. *Under any **informative** report r, the loan officer's communication strategy must satisfies $Pr(m = h|\theta = H) = 1$ and $Pr(m = l|\theta = L) \in (0, 1]$.*

Lemma 2 states that if the report is *informative*, then a loan officer is always honest after seeing a high type borrower but may lie after seeing a low type borrower. Firstly, following Proposition 2 from Bester and Strausz (2001), a loan officer must be honest with positive probability, ruling out cases where a loan officer lies almost surely after seeing the borrower's type. Given the wage structure, I can further demonstrate that in equilibrium, the loan officer must be honest for at least one type of borrower since it cannot be the case that the loan officer is indifferent between loan approval and rejection for both types of borrowers. Next, I demonstrate that the loan officer must be honest after seeing a high type borrower. This is because the bank could always better off by altering the information system to make r more informative about good state, while still providing sufficient incentive to motivate high pre-screening efforts.

The next lemma identifies the condition when an informative report exists.

Lemma 3. *If there exists an* ***informative*** *report* r*, then it must be* $zp_G(R - w_s) < k - w_0$.

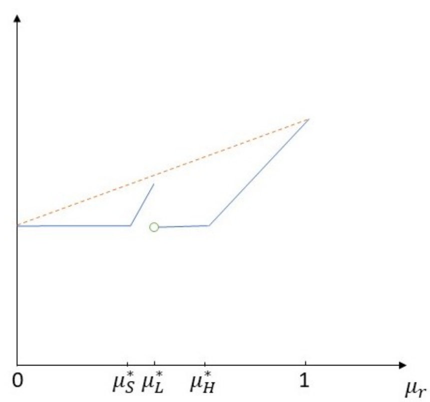


Figure 4.2: Optimal information system with soft information if $zp_G(R-w_s) \geq k-w_0$. The solid line is the bank's expected payoff conditional on belief μ_r. The dashed line represents the concavification of the bank's expected payoff.

Lemma 3 demonstrates that if there is a signal realization that is *informative*, then the bank must reject low type borrowers regardless of the hard information report. When approval is optimal for low types under good states, the bank's payoff is maximized with a perfect information system that has no truth-telling or incentive compatibility constraints, given the convexity of the bank's payoff function with respect to borrowers' types. Since loan approval decisions do not depend on borrowers' type under a perfect information system, truth-telling constraints are satisfied for both types of borrowers. Moreover, given that a loan to an low type borrower yields negative NPV, approving loan for low types under good state implies expected wage payments to the loan officer is lower than the fixed payment w_0 to the loan officer when the loan is rejected. Hence, the loan officer's expected gain from undertaking $e = 1$ would be higher under a perfect reporting system. This result demonstrates that if approval is optimal for low type under good state, the bank should use a perfect information system and rely on hard information only.

An implication of Lemma 3 is that, within the set of equilibrium containing at least one *informative* report, it is sufficient to consider reporting realizations with posterior $\mu_r \leq \min\{1, \frac{w_0}{zp_G w_s}\}$. For all informative reports r, truth-telling is the unique optimal response if $\mu_r < \min\{1, \frac{w_0}{zp_G w_s}\}$. Moreover, when $\mu_r = \frac{w_0}{zp_G w_s}$, a loan officer with a low type borrower is indifferent between sending message $m = l$ or $m = h$. This suggests that truth-telling is sustainable for all *informative* reports regardless of wage contracts. Given that the bank's payoff is maximized if the loan officer is honest, I can exclusively focus on truth-telling outcomes under any *informative* reports. Moreover, for all reports with $\mu_r > \min\{1, \frac{w_0}{zp_G w_s}\}$, truth-telling is an optimal response for a loan officer with a low type borrower if and only if the bank's response to loan officer's message is indifferent to loan officer's message, which implies for all reports with $\mu_r > \min\{1, \frac{w_0}{zp_G w_s}\}$, the bank's payoff is equivalent to the case of babbling. Following the extended version of revelation principle, I can exclude all report realizations with posterior $\mu_r > \min\{1, \frac{w_0}{zp_G w_s}\}$ thus concentrating exclusively on truth-telling equilibrium.

I now characterize the optimal contract and information system under soft information lending. I will start by characterizing the optimal contract for any information system that is consistent with Proposition 4. Then, I will determine the information system that maximizes the bank's payoff. Proposition 5 provides a summary of both the optimal contract and the optimal information system.

Proposition 4. *Under soft information lending, the optimal information system has two signal realizations* $\mathbb{R} = \{g, b\}$ *given any contract inducing* $e = 1$ *such that:*

- $\mu_b = 0$;
- $\mu_g = \min\{1, \frac{w_0}{zp_G w_s}\}$.
- *Bank approves loan if* $r = g$ *and* $m = H$ *and rejects otherwise.*

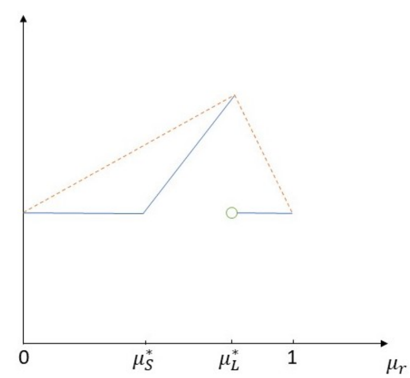


Figure 4.3: Optimal information system with soft information. The solid line is the bank's expected payoff conditional on belief μ_r. The dashed line represents the concavification of the bank's expected payoff.

Proposition 4 states that for soft information lending, I can restrict my interest to an information system with only two signal realizations: $\mathbb{R} = \{g, b\}$, such that b signal reveals B signal reveals state B perfectly, and g signal reveals state G with a positive probability. The loan is approved with a g signal if the borrower is an H-type. Based on Lemma 3, I can focus on two types of signals: those that result in the bank approving the loan for the H-type borrower and those that do not. To induce the loan officer to exert high effort, there must be at least one signal that results in the bank approving the loan for an H-type borrower. Given this condition and the truth-telling constraint, there is an upper bound on the posterior probability of G state for all feasible signals conditional on wage payments (w_s, w_0). However, once this constraint is in place, the bank's payoff function under feasible posteriors becomes convex again. Therefore, the bank's payoff is maximized with the most informative system subject to the constraint on the upper bound of potential posteriors. We can further show that the loan officer's expected gain from undertaking $e = 1$ is higher under this information system.

Proposition 5. *Under soft information lending, if the bank wants to induce the loan officer to undertake effort* $e = 1$, *the optimal compensation satisfies* $w_s^* = \frac{c}{\Delta p_0 p_G (1-z)}$ *and* $w_0^* = \frac{\mu^* z c}{\Delta p_0 (1-z)}$ *with:*

- $\mu^* = \underline{\mu}$ *if* $p_0 \sqrt{\frac{\Delta q(1-z)k}{zc}} \leq \underline{\mu}$;
- $\mu^* = p_0 \sqrt{\frac{\Delta q(1-z)k}{zc}}$ *if* $p_0 \sqrt{\frac{\Delta q(1-z)k}{zc}} \in (\underline{\mu}, 1)$;
- $\mu^* = 1$ *if* $p_0 \sqrt{\frac{\Delta q(1-z)k}{zc}} \geq 1$,

where $\underline{\mu} = \max\{p_0, \frac{\Delta p_0 k}{\Delta p_0 p_G R - c}\}$. *The optimal information system satisfies* $\mu_g = \mu^*$.

I first demonstrate that under soft information lending, w_0 makes the loan officer indifferent about loan approval decisions when signal realization from the information system is g given any w_s. Hence, there is an one-to-one mapping between w_0 and w_s. Then, I substitute the value of w_0 given w_s into the incentive compatibility constraint for any information system satisfying Proposition 4. Finally, I will determine the optimal informativeness level of g signal about G state, which would give us the optimal contract and information system inducing $e = 1$ from the loan officer. The key economic trade-off determining the optimal contract and information system under soft information regime is the trade-off between better information (precision of $r = g$) and the cost to induce truth-telling, as w_0 is strictly increasing in the posterior μ_g.

Next, I will examine the optimal level of effort that the bank aims to induce under soft information lending. If it is optimal to induce the loan officer to undertake $e = 1$, we must have

$$q\{\frac{p_0}{\mu^*}[\mu^* p_G(R - w_s^*) - k] - (1 - \frac{p_0}{\mu^*})w_0^*\} - (1-q)w_0^* \geq (q - \Delta)p_0(p_G R - k). \tag{4.3}$$

which implies

$$\Delta p_0 p_G R - q\frac{p_0}{\mu^*}k + (q - \Delta)p_0 k \geq \frac{qc}{\Delta} + \frac{\mu^* zc}{\Delta p_0(1-z)}. \tag{4.4}$$

Compared to the first-best benchmark, there are two major differences. First, the implicit investment cost is higher, as g is no longer a perfect indicator about good economic state. Second, the cost to incentivize the loan officer is increased by w_0^*, as a positive w_0 is necessary to ensure L types reveal their true types. The following corollary outlines conditions when it is optimal to induce $e = 1$ under soft information lending regime.

Corollary 1. *Under soft information lending, it is optimal to induce* $e = 1$ *if: (1)* c *is small; (2)* Δ *is large; (3)* q *is small; (4)* p_0 *is large; (5)* z *is small.*

4.4 Equilibrium

This section examines the bank's initial decision-making process concerning the information regime and the desired level of effort it aims to elicit from the loan officer. My first observation is that if the bank wants to induce $e = 0$, it will always prefer a soft information regime. In this case, since there is no need for incentive compensation, the bank's only objective is to maximize the NPV of the loan, which is achieved by using all information available, regardless of regardless of its nature, *i.e.*, whether it is soft or hard. The next step is to establish the condition under which the bank prefers $e = 1$, irrespective of the chosen information regime.

$$[q + (1-q)z][p_G(R - \frac{c}{\Delta p_0 p_G(1-z)}) - k] \geq (q - \Delta)(p_G R - k) \tag{4.5}$$

Corollary 2. *It is optimal for the bank to induce $e = 1$ without using soft information if: (1) c is small; (2) Δ is large; (3) p_0 is large; (4) z is large.*

I now consider the bank's preference over information regimes conditional on the loan officer undertaking $e = 1$. If the bank wants to induce truthful communication, the following inequality,

$$\begin{aligned} & q\{\frac{p_0}{\mu^*}[\mu^* p_G(R - \frac{c}{\Delta p_0 p_G(1-z)}) - k] - (1 - \frac{p_0}{\mu^*})\frac{\mu^* zc}{\Delta p_0(1-z)}\} - (1-q)\frac{\mu^* zc}{\Delta p_0(1-z)} \\ \geq & p_0\{[q + (1-q)z]p_G(R - \frac{c}{\Delta p_0 p_G(1-z)}) - k\}, \end{aligned}$$

must holds, which could be reorganized as

$$\begin{aligned} & \underbrace{\frac{zc}{\Delta(1-z)}(\frac{\mu^*}{p_0} - 1)}_{\text{Additional compensation cost to elicit soft information}} + \underbrace{q(\frac{p_0}{\mu^*} - p_0)k}_{\text{Overinvestment under soft info. regime}} \\ \leq & \underbrace{(1-q)p_0(k - zp_G R)}_{\text{Overinvestment under hard info. regime}} . \end{aligned} \tag{4.6}$$

The following proposition characterizes conditions under which the bank prefers soft information lending.

Proposition 6. *Suppose the bank always wants to induce $e = 1$ from the loan officer, it prefers soft information regime if: (1) c is small; (2) Δ is large; (3) q is small; (4) p_0 is large; (5) z is small.*

Proposition 6 is based on two channels as indicated in equation (6). The first channel concerns the impact of model parameters on the cost of additional compensation to induce truthful communication of soft information from the loan officer. Proposition 5 shows

Table 4.1: Comparative statics on relative costs of soft information regime

Parameter	Additional compensation cost	Relative overinvestment cost
$c \uparrow$	$\uparrow$	$\uparrow$
$\Delta \uparrow$	$\downarrow$	$\downarrow$
$q \uparrow$	$\uparrow$	$\uparrow$
$p_0 \uparrow$	$-(\downarrow \textit{when}\, \mu^* \equiv 1)$	$\downarrow$
$z \uparrow$	$\uparrow$	$\uparrow$

that it is cheaper to elicit truthful communication when c is small, Δ is large, p_0 is large, or z is small. Intuitively, when effort cost is low, or the ex-ante difference in outcomes for different effort levels is high enough, the bank does not need to provide high-powered incentives to induce effort, reducing the additional payments required for the loan officer to truthfully communicate soft information. The second channel considers the cost of inefficient overinvestment in two regimes, given the efficient level of effort exerted by the loan officer. Ignoring soft information is more costly when q is small or z is small, as the propensity of L-type borrowers increases or the NPV of an L-type project decreases. Interestingly, a higher prior about G state favors soft information lending because the likelihood of overinvestment under hard information regime increases when p_0 is higher, while the incidence of overinvestment under soft information regime decreases.

Chapter 5

Discussions

5.1 Discussions of Assumptions

In this section, I examine how modifying certain assumptions may impact our findings and how certain assumptions may be linked to real-world practices.

5.1.1 Delegation

In the main setting, I assumed that the bank headquarter has the authority to sanction new loan applications. Given that the loan officer has private information and the loan officer may have different preference over loan approval decisions with the bank, it is natural to ask what happens if the bank delegates the loan approval decision to the loan officer. In reality, the delegation of loan approval authority to loan officers is a prevalent practice, particularly for loans of smaller magnitudes.

Instead of directly making loan approval decisions, now I assume that the bank allows the loan officer to choose from the decision set $\{Approval, Rejection\}$. In this context, the bank designs a contract $\{w_s, w_0\}$ and information system $\mathbb{R}$ to maximize its payoff. Suppose under any signal realization r, the loan officer approves the loan application if $\mu_r p_G w_s > w_0$ and rejects the loan application otherwise. It becomes evident that under hard information regime, delegation results in the same outcome as if the bank approves the loan application. This equivalence arises from the choice of setting $w_s = 0$, which guarantees that the loan officer invariably approves the loan whenever μ_r is positive. Furthermore, as the delegation set is the same as the bank's decision set with a centralized loan committee, it's possible to execute a direct mechanism consistent with the revelation principle via delegation (Hölmstrom, 1977, 1984), which implies the delegation problem is akin to a scenario where the bank can pre-commit to loan approval decision rules and enshrine them in contracts.

From the above discussion, one can see that the soft information framework can also be realized through delegation, using the same contract and information system as established in the main setting. Yet, it is worth noting that under delegation regime, the loan officer may approve loan applications for high-type borrowers when information about state is sufficiently positive, even if such approval decision is sub-optimal for the bank. However, so long as the private cost of effort for the loan officer is low, the delegation approach could yield outcomes congruent with those of a centralized loan committee even if the bank cannot commit to loan approval rules ex-ante.

5.1.2 Authority over Information Design

In the main setting, I assumed that the bank was responsible for the design of the information system and the loan officer's compensation contract. In this section, I examine a scenario where the loan officer, instead of the bank, is in charge of the design of information system at $t = 0$. As the main setting, the optimal contract to induce $e = 0$ is to offer $w_s = w_0 = 0$, so we will concentrate only on contracts inducing $e = 1$.

Proposition 7. *Suppose the bank offers a contract such that $w_0 < zp_G w_s$. If inequality (4.5) holds, then the loan officer always implements a fully informative information system if he is in charge of information design and undertakes $e = 1$.*

Surprisingly, under certain conditions, the loan officer prefers a perfect information

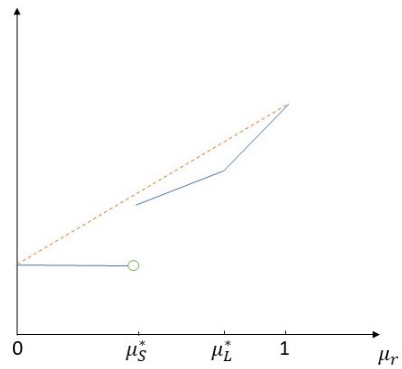


Figure 5.1: Optimal information system when loan officer is in charge of information design. The solid line is the loan officer's expected payoff conditional on belief μ_r. The dashed line represents the concavification of the loan officer's expected payoff.

system at $t = 0$, while the bank prefers an imperfect one. When w_0 is sufficiently small, the loan officer prefers to approve the loan even if the borrower is an L-type. If the bank approves the loan under good states without knowledge about the borrower's type, the loan officer would not share information about the borrower's type with the bank if it leads to the rejection of a loan application. Furthermore, when w_0 is small, the loan officer's payoff becomes an increasing and convex function of the posterior probability about good states. Thus, the loan officer always benefits from a more informative information system.

Proposition 7 has two implications. First, if the bank only relies on hard information for loan approval, the bank would offer the same contract to the loan officer, regardless of who designs the information system. This is because, according to Proposition 3, if the bank wants to induce $e = 1$ under hard information regime, w_0 must be set to zero, indicating that a fully informative information system is also optimal for the loan officer. Second, if the NPV of the loan under good states is sufficiently high without information about the borrower's type, the only contract that can induce induce high pre-screening efforts and information sharing is to set $w_0 = zp_G w_s$. To facilitate information sharing, the bank must make it optimal for the loan officer to share information even if he knows $\eta = G$ perfectly.As a result, inducing information sharing may be more expensive if the loan officer is responsible for information system design, leading the bank to prefer relying only on hard information for loan approval.

5.1.3 Timing of information transmission

In the first best scenario, if the bank possesses information about the borrower's type in advance, it would utilize a perfect information system for loan approval decisions. This raises the question of whether the bank can gain advantages by customizing the information system and loan approval criteria based on the loan officer's reports of borrowers' types. Thus, in this subsection, I examine an alternative timeline of information transmission, wherein the loan officer first reports the borrower's type, and then the bank uses a predetermined information system that is contingent on the loan officer's report to make loan approval decisions.

In accordance with Kolitilin et.al. (2017), we differentiate mechanisms as either a *persuasion mechanism* or an *experiment mechanism* based on whether the information system is conditioned on loan officers' reports. In our main setting, the mechanism we studied is an *experiment mechanism* since it does not necessitate the loan officer to report their private information first. On the other hand, the *persuasion mechanism* can be defined as follows.

Definition 2. *A* ***persuasion mechanism*** *asks the loan officer to report $m \in \mathbb{M}$ and then reports signal $r \in \{g, b\}$: for each r and m, $p_{gm} = Pr(r = g|m)$ and $\mu_{rm} = Pr(\eta = G|m, r)$, loan is approved if $r = g$ and rejected if $r = b$.*

As the main setting, the optimal contract to induce $e = 0$ is to offer $w_s = w_0 = 0$. Additionally, based on the revelation principle, we can concentrate on *persuasion mechanisms* where the loan officer truthfully reveals the borrower's type.

Definition 3. *A persuasion mechanism is* ***incentive compatible*** *if the loan officer finds it optimal to undertake $e = 1$ and report the true type of the borrower.*

Kolitilin et.al. (2017) demonstrated that in linear environments, a sender does not need to tailor information disclosure to a receiver's report when the receiver possesses private information. Since the compensation structure in this paper bears resemblance to a linear environment, it is not unexpected that the timing of information transmission does not impact my findings.

Proposition 8. *Given any pair* (w_s, w_0)*, an incentive compatible persuasion mechanism can be implemented by an experiment mechanism.*

The proof of Proposition 8 bears some similarities to that of Lemma 3. I establish that when it is optimal to approve loans for low type borrowers under good states, the optimal information system is fully informative and independent of borrowers' types. The bank's payoff is again shown to be convex with respect to posteriors about the state, regardless of borrowers' types. The truth-telling constraints hold under perfect information systems since loan approval decisions are not contingent on borrowers' types. We also demonstrate that the loan officer's expected gain from exerting efforts is higher under a perfect reporting system due to the lower expected wage payment for low types under good state than the fixed payment w_0 received when loan is rejected, given that loan approval for low types is optimal under good states. Consequently, if a persuasion mechanism exists that makes information acquisition type-dependent, then the loan application would be rejected when the loan officer reports that the borrower is an low type. However, if that is the case, then the conditional information policy when the loan officer reports an low type is inconsequential, and the bank can always achieve the same expected payoff by adopting the information policy that is uniformly conditional on an high type borrower.

5.1.4 Information structure

One major limitation to my model is that the complexity that arises when adding an additional state in which the loan has a positive net present value for both types, rendering the optimal disclosure strategy intractable. As demonstrated in the main setting, the bias in communication endogenously arises through incentive contracting, which is used to motivate loan officers' efforts. The information system is designed to reduce the loan officer's incentive to deceive about the borrower's type, while still promoting effort exertion. However, after introducing a third state where the project yields positive NPV for both types, the disclosure strategy maximizing the bank's payoff under a fixed level of effort undertaken by the loan officer could induce the loan officer to shirk ex-ante. Therefore, the optimal information system design must also consider the loan officer's effort incentives, making it impossible to fully characterize the optimal reporting system.

However, in my banking setting, the two-state structure for hard information can be viewed as a way to measure risk. As noted by Stulz (2022), one of the main objectives of current risk management practices in the banking industry is to limit exposure to downside risks, that is, the possibility of unfavorable outcomes. From this perspective, the "bad" state in our paper could be seen as a scenario where it never makes sense for the bank to approve any loan application, regardless of soft information about borrowers. Conversely, the "good" state corresponds to a scenario where granting a loan to a good borrower could result in a positive net present value. However, the fact that a good borrower could still fail in the "good" state indicates the presence of unknown or unanticipated risks.

5.1.5 Timing of efforts

In this subsection, I examine an alternative timeline for all events. I now suppose that the loan officer exerts effort e after reporting r is realized. Again we focus exclusively on contracts where $e = 1$ could be induced under certain signal realizations.

First, the optimal information system without communication remains unchanged regardless of when efforts are exerted. Intuitively, efforts are irrelevant under bad states, as the project would not be approved irrespective of the borrower's type. Hence, effort should only be induced under sufficiently good signal realizations. Furthermore, the payment to the loan officer conditional on successful repayment should decrease as the good signal becomes more informative since a more informative good signal reduces the loan officer's uncertainty about the state, thus increasing his expected compensation after the effort is undertaken, given a fixed payment schedule. Therefore, the bank's expected payoff when the loan is approved would be increasing on the precision of signal about the good state given any payment schedule.

Moving on to the scenario with effective communication, I obtain a result significantly differing from the main setting: a fully informative system is optimal even if the bank wants to induce truth-telling from its loan officers when the loan officers exert efforts after r is realized. The key difference lies in the fact that when effort is undertaken ex-post„ *i.e.*, after r is realized, the loan officer's expected gain from undertaking high efforts is directly influenced by μ_g, the posterior belief about the probability that state G is realized conditional on $r = g$, rather than the ex-ante belief p_0 about the probability of state G. This can be seen by comparing the incentive compatibility constraint for taking effort between these two scenarios, while taking into account the binding truth-telling constraint. When effort is undertaken ex-ante, the incentive compatibility for effort is:

$$\Delta p_0 p_G (1 - z) w_s \geq c. \tag{5.1}$$

The incentive compatibility constraint when the effort is undertaken ex-post is:

$$\Delta \mu_g p_G (1 - z) w_s \geq c. \tag{5.2}$$

Comparing (5.1) and (5.2), we can see that when the effort is exerted ex-ante, the equilibrium payment w_s^* does not depend on μ_g, the posterior belief about good state after seeing $r = g$. However, given the truth-telling constraint, this implies w_0^* is increasing on μ_g, which implies more precise information makes truth-telling more costly. Instead, when the effort is undertaken ex-post, higher μ_g reduces equilibrium w_s^* but does not affect w_0^*, which implies higher μ_g would reduce the payment to the loan officer once the loan is successfully repaid. Thus, the bank should always establish a fully informative system when effort is exerted after r is realized.

In appendix B I formally characterize the results described above. This result highlights the importance of the ex-ante effort assumption for the loan officer.[1]

5.2 Empirical Relevance

5.2.1 Zombie Lending

In real-world scenarios, it is a common occurrence for banks to grant loans to zombie firms that consistently generate operating cash flows lower than their interest payments[2]. Zombie lending distorts credit allocation and has detrimental effects on aggregate investments and productivity. Researchers have argued that zombie lending played a significant role in Japan's "lost decades" in the 1990s[3] and the sluggish economic recovery in Europe after debt crisis[4]. The puzzling aspect is that zombie firms can be easily identified using publicly available information (Especially, cash flow is easy to verify by third parties), making it unclear why banks engage in such practices.

Various explanations have been put forth in existing literature to account for this phenomenon. One explanation revolves around bank capital requirements. Ending a nonperforming loan negatively impacts a bank's capital, potentially triggering regulatory actions or even bank closure. Consequently, banks are reluctant to acknowledge losses by writing off bad loans, particularly when they are already under financial strain and seek to avoid or delay balance sheet repercussions. However, this explanation falls short in explaining why zombie lending occurs even among well-capitalized banks, as demonstrated by examples such as First NBC Bank, which engaged in zombie lending practices before its failure in

[1] It can be further shown that adopting a soft information regime is always optimal with ex-post effort.

[2] Banerjee and Hofmann (2018) find that zombie firms make up about 12% of all publicly traded firms across 14 advanced economies.

[3] See Caballero, Hoshi, and Kashyap (2008), Peek and Rosengren (2005)

[4] See Acharya et al. (2019) and Blattner, Farinha, and Rebelo (2023)

2017, despite being considered well capitalized from 2006 to February 2015, according to the FDIC report.

Another explanation focuses on asymmetric information. Hu and Varas (2021) argued that asymmetric information is developed between the bank/entrepreneur and the market during the continuation of lending relationship, and the bank would roll over loans even after learning bad news for the prospect of future market financing when the entrepreneur has accumulated sufficient reputation through the lending relationship.

This paper also sheds light on the role of asymmetric information in zombie lending but introduces a different channel. Instead of information asymmetry between the bank and the market, my results suggest that zombie lending can arise due to an internal multi-task agency problem within the bank itself, specifically between loan officers and the bank headquarters. Loan officers are responsible for screening potential borrowers, and this screening process can enhance the overall quality of borrowers. However, loan officers could obtain soft information that is unfavorable for the borrower. Incentive compensation schemes designed to encourage screening efforts can inadvertently distort the loan officer's incentive to disclose negative soft information about borrowers. Consequently, when soft information becomes crucial in evaluating borrowers, it may be optimal for the bank to engage in self-limiting zombie lending. This strategy simultaneously reduces compensation costs to motivate screening efforts and encourages loan officers to honestly disclose their private soft information about borrowers.

5.2.2 Information Usage in Bank Lending and Loan Officer Compensation

The effect of soft information on loan quality is ambiguous. Previous studies has shown that soft information allows loan officers to better screen borrowers and thus enhances the quality of their loan decisions (e.g., Petersen and Rajan, 1994; Berger and Udell, 2002; Petersen, 2004). While other studies has found evidence that cognitive constraints and behavioral biases impede the processing and interpretation of soft information in private lending and could lead to worse loan quality (Campbell et al., 2019).

In an experimental setting, Cole, Kanz, and Klapper (2015) find that high-powered incentives lead to greater screening effort, and compensation structure have significant impacts on loan officers' subjective perception of credit risk. These experimental results are consistent with my insight from this paper that multitasking problem could impede the transmission of soft information in bank lending decisions.

Cole, Kanz, and Klapper (2015) also finds that career concerns could lead to higher screening effort from loan officers. Putting in my model, career concerns lower the private cost of efforts. Therefore, I predict that the bank would more likely to use soft information in bank lending decisions when its loan officers has higher career concerns.

Chapter 6

Conclusion

I propose a model of bank lending in which loan officers must exert costly effort to screen new applicants and communicate soft information with the headquarters. The headquarter is responsible for designing a compensation scheme and implementing an information system that generates decision-relevant information. As the bank faces a multi-task agency problem with its officers, it must balance the trade-off between higher base wage payments and the loss of decision-relevant information to minimize total losses.

I identify conditions when the bank would prefer to ignore the loan officer's soft information about borrowers and when the bank would substitute the information system's informativeness (positive biased) for lower base payment (when a loan application is rejected) to elicit communication. As the cost of motivating effort increases, the bank would first compromise the informativeness of the information system, and then restore a fully informative system while ignoring soft information altogether. Additionally, I discover that under certain conditions, the loan officer would favor a fully informative system so that he could conceal soft information about the borrower when he is in charge of information design.

Introducing a dynamic extension to my model that incorporates the well-known "sunk cost effects" could generate novel insights on bank lending practices. In numerous real-world cases, the decision maker discovers new information that switching project would be optimal but still continue to invest resources in the failed ones. The explanation for this phenomenon is primarily based on psychological factors[1] except for Kanodia et.al (1989), which is based on private information and reputation concern about managers' human capital due to information asymmetry.

In practical scenarios, soft information often emerges after the lending relationship has been established. Sunk cost effects imply that loan officers may withhold unfavorable soft information to avoid triggering a loan recall when borrowers miss installment payments. The dynamic extension of my model could be utilized to examine the relationship between "sunk cost effects" and zombie lending practices. Since extending my current model in this direction is not a straightforward task, it is left for future research.

[1]See Staw and Ross (1986) for a comprehensive review.

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Appendix A

Proof of Propositions and Lemmas

A.1 Proof of Lemma 1

Proof. The bank's optimization problem is

$$\begin{aligned} \min_{w_s, w_0} \quad & qp_0p_Gw_s + [1 - qp_0]w_0 \\ \text{s.t.} \quad & \Delta p_0p_Gw_s \geq \Delta p_0w_0 + c \quad [\lambda_1] \\ & w_s \geq 0 \quad [\lambda_2] \\ & w_0 \geq 0 \quad [\lambda_3]. \end{aligned}$$

The corresponding Lagrange multipliers are in square brackets. The first-order conditions after some manipulations with respect to w_s and w_0 are:

$$-qp_0p_G + \lambda_1\Delta p_0p_G + \lambda_2 = 0; \tag{A.1}$$

$$qp_0 - 1 - \lambda_1\Delta p_0 + \lambda_3 = 0. \tag{A.2}$$

Given non-negativity of both w_s and w_0, incentive compatibility can hold if and only if $w_s > 0$, which implies $\lambda_2 = 0$. As a result, we must have

$$qp_0p_G = \lambda_1 \Delta p_0 p_G \tag{A.3}$$

which implies $\lambda_3 = 1$. Hence, in equilibrium, we must have $w_0 = 0$. Furthermore, from (A.1) we know that $\lambda_1 = \frac{q}{\Delta} > 0$, which implies incentive compatibility must bind. Inserting $w_0 = 0$, we could obtain $w_s = \frac{c}{\Delta p_0 p_G}$. □

A.2 Proof of Proposition 1

Proof. Suppose not, then there exists an information system with some report realization r with $\mu_r \in (0,1)$ such that the loan officer would undertake $e = 1$. We show that such report r is dominated by an alternative reporting strategy reports either $r = G$ or $r = B$ perfectly. As there must exist one report realization such that the loan is approved, we only need to consider the case where loan is approved under $r = G$ and rejected under $r = B$, which implies

$$[q + (1-q)z]p_G(R - w_s) \geq k - w_0. \tag{A.4}$$

Denote the bank's payoff under the existing reporting system as π_B and its payoff under the alternative reporting system as π'_B. Denote the probability that r realizes as p_r. Denote the loan officer's payoff under existing reporting system as π_{Oe} and his payoff under alternative reporting system as π'_{Oe} where e is the effort level. We consider two cases differentiated by whether a loan is approved under r.

Case 1: Loan is rejected under r

We first show that the bank's payoff is higher under the alternative reporting system.

Notice that

$$\begin{aligned}\pi_B' - \pi_B &= p_r\{\mu_r[q + (1-q)z]p_G(R - w_s) + (1-\mu_r)(k - w_0)\} - p_r(k - w_0)\\ &= p_r\mu_r\{[q + (1-q)z]p_G(R - w_s) - (k - w_0)\}\\ &\geq 0,\end{aligned}$$

where the last inequality is the direct result of (6). Thus, the bank's payoff is always higher under an alternative reporting system.

We now show that the incentive compatibility constraint still holds for the loan officer under the new reporting system. We have

$$\begin{aligned}\pi_{O1}' - \pi_{O1} &= p_r\{\mu_r[q + (1-q)z]p_G w_s + (1-\mu_r)w_0\} - p_r w_0\\ &= p_r\mu_r\{[q + (1-q)z]p_G w_s - w_0\},\end{aligned}$$

and

$$\begin{aligned}\pi_{O0}' - \pi_{O0} &= p_r\{\mu_r[q - \Delta + (1-q+\Delta)z]p_G w_s + (1-\mu_r)w_0\} - p_r w_0\\ &= p_r\mu_r\{[q - \Delta + (1-q+\Delta)z]p_G w_s - w_0\},\end{aligned}$$

which implies

$$\pi_{O1}' - \pi_{O1} - (\pi_{O0}' - \pi_{O0}) = p_r\mu_r\Delta(1-z)p_G w_s > 0. \tag{A.5}$$

(A.5) indicates that the incentive compatibility constraint would hold under the alternative reporting strategy if it holds under the old reporting system. Hence, we conclude that the alternative reporting strategy is indeed optimal.

Case 2: Loan is approved under r

Again, we first show that the bank's payoff is higher under the alternative reporting system. Notice that

$$\begin{aligned}\pi'_B - \pi_B =& p_r\{\mu_r[q+(1-q)z]p_G(R-w_s) + (1-\mu_r)(k-w_0)\}\\ &- p_r\mu_r[q+(1-q)z]p_G(R-w_s)\\ =& p_r(1-\mu_r)(k-w_0)\\ >& 0,\end{aligned}$$

so the bank's payoff is always higher under the alternative reporting system.

We now show that the incentive compatibility constraint still holds for the loan officer under the new reporting system. We have

$$\begin{aligned}\pi'_{O1} - \pi_{O1} &= p_r\{\mu_r[q+(1-q)z]p_G w_s + (1-\mu_r)w_0\} - p_r\mu_r[q+(1-q)z]p_G w_s\\ &= p_r(1-\mu_r)w_0,\end{aligned}$$

and

$$\begin{aligned}\pi'_{O0} - \pi_{O0} &= p_r\{\mu_r[q-\Delta+(1-q_0+\Delta)z]p_G w_s + (1-\mu_r)w_0\} - p_r\mu_r[q_0-\Delta+(1-q_0+\Delta)z]p_G w_s\\ &= p_r(1-\mu_r)w_0,\end{aligned}$$

which implies

$$\pi'_{O1} - \pi_{O1} = \pi'_{O0} - \pi_{O0}. \tag{A.6}$$

(A.6) indicates that the incentive compatibility constraint would hold under the alternative reporting strategy if it holds under the old reporting system. Hence, we conclude that the alternative reporting strategy is indeed optimal. □

A.3 Proof of Proposition 2

Proof. The bank's optimization problem is

$$\begin{aligned}
\min_{w_s, w_0} \quad & p_0[q+(1-q)z]p_G w_s + (1-p_0)w_0 \\
\text{s.t.} \quad & p_0[q+(1-q)z]p_G w_s \geq p_0[q-\Delta+(1-q+\Delta)z]p_G w_s + c \quad [\lambda_1] \\
& w_s \geq 0 \quad [\lambda_2] \\
& w_0 \geq 0 \quad [\lambda_3] \\
& [q+(1-q)z]p_G(R-w_s) \geq k - w_0 \quad [\lambda_4].
\end{aligned}$$

The corresponding Lagrange multipliers are in square brackets. The first-order conditions after some manipulations with respect to w_s and w_0 are:

$$-p_0[q+(1-q)z]p_G + \lambda_1 \Delta p_0 p_G(1-z) + \lambda_2 - \lambda_4[q+(1-q)z]p_G = 0; \tag{A.7}$$

$$-(1-p_0) + \lambda_3 + \lambda_4 = 0. \tag{A.8}$$

Given the non-negativity of both w_s and w_0, incentive compatibility can hold if and only if $w_s > 0$, which implies $\lambda_2 = 0$. Now we claim $\lambda_1 > 0$. Suppose not, then we must have $\lambda_4 = -p_0 < 0$, which is a contradiction. Hence, in equilibrium, incentive compatibility constraint must bind, which implies

$$w_s = \frac{c}{\Delta p_0 p_G (1-z)}.$$

Now we characterize w_0. If we have $[q+(1-q)z]p_G(R-\frac{c}{\Delta p_0 p_G(1-z)}) \geq k$, then regardless of our choice of w_0, the bank would always approve the loan when $r = G$, which implies $w_0 = 0$. If we have $[q+(1-q)z]p_G(R-\frac{c}{\Delta p_0 p_G(1-z)}) < k$, then in equilibrium we must have $w_0 > 0$, otherwise the bank would not approve the loan even if $r = G$. Under this scenario, we must have $\lambda_3 = 0$ and $\lambda_4 = 1-p_0 > 0$, which implies $w_0 = k-[q+(1-q)z]p_G(R-\frac{c}{\Delta p_0 p_G(1-z)})$. □

A.4 Proof of Proposition 3

Proof. We consider two cases based on whether $[q-\Delta+(1-q+\Delta)z]p_G R \geq k$.

Case 1: $[q-\Delta+(1-q+\Delta)z]p_G R < k$

As the bank never approves the loan if the loan officer exerts $e=0$, $e=1$ is optimal if:

$$p_0\{[q+(1-q)z]p_G(R-\frac{c}{\Delta p_0 p_G(1-z)})-k\}-(1-p_0)w_0 \geq 0. \tag{A.9}$$

If $w_0=0$, then (A.9) is equivalent to

$$[q+(1-q)z]p_G(R-\frac{c}{\Delta p_0 p_G(1-z)}) \geq k, \tag{A.10}$$

which is the same condition for $w_0=0$. If $w_0>0$, then inserting w_0 to (A.9) would give us

$$w_0 \leq 0, \tag{A.11}$$

which is a contradiction.

Case 2: $[q-\Delta+(1-q+\Delta)z]p_G R \geq k$

As the bank always approves the loan under $\eta=G$ if the loan officer exerts $e=0$, $e=1$ is optimal if:

$$\begin{aligned} &p_0\{[q+(1-q)z]p_G(R-\frac{c}{\Delta p_0 p_G(1-z)})-k\}-(1-p_0)w_0 \\ \geq &p_0\{[q-\Delta+(1-q+\Delta)z]p_G R-k\}. \end{aligned} \tag{A.12}$$

If $w_0=0$, then (A.12) is equivalent to

$$[q+(1-q)z]p_G(R-\frac{c}{\Delta p_0 p_G(1-z)}) \geq [q-\Delta+(1-q+\Delta)z]p_G R, \tag{A.13}$$

where the condition for $w_0 = 0$ is satisfied given $[q - \Delta + (1 - q + \Delta)z]p_G R \geq k$. If $w_0 > 0$, then inserting w_0 to (A.12) would give us

$$w_0 \leq -p_0\{[q - \Delta + (1 - q + \Delta)z]p_G R - k\} < 0, \tag{A.14}$$

which is a contradiction.

Combining two cases imply that inducing $e = 1$ is optimal if

$$[q + (1 - q)z]p_G(R - \frac{c}{\Delta p_0 p_G(1 - z)}) \geq \max\{k, [q - \Delta + (1 - q + \Delta)z]p_G R\}.$$

□

A.5 Proof of Lemma 2

Proof. I first show that for any *informative* report r, the loan officer's communication strategy must satisfy either $Pr(m = h|\theta = H) = 1$ or $Pr(m = l|\theta = L) = 1$. Suppose not, then under report realization r, it must be $Pr(m = h|\theta = H) \in (0, 1)$ and $Pr(m = l|\theta = L) \in (0, 1)$ by Proposition 2 of Bester and Strausz (2001). This implies $\mu_r p_G w_s = w_0$ and $\mu_r z p_G w_s = w_0$ must hold simultaneously, which is a contradiction as $z < 1$.

I now show that $Pr(m = h|\theta = H) = 1$ for any informative r. Suppose not, then I must have both $Pr(m = h|\theta = H) \in (0, 1)$ and $Pr(m = l|\theta = L) = 1$, which implies $\mu_r p_G w_s = w_0$ and $\mu_r z p_G w_s < w_0$. Now consider an alternative reporting system, instead of generating r, generating two signals $\bar{r}$ and $\underline{r}$ such that $\mu_{\underline{r}} = 0$ and $\mu_{\bar{r}} \in (\mu_r, \frac{\bar{\mu}}{z})$ with $\bar{\mu} = \min\{1, \frac{k - w_0}{p_G(R - w_s)}, \frac{w_0}{p_G w_s}\}$. Accordingly, the probability of signal $\bar{r}$ is $\frac{\mu_r}{\mu_{\bar{r}}}$ and the probability of signal $\underline{r}$ is $1 - \frac{\mu_r}{\mu_{\bar{r}}}$.

It is easy to verify that under signal $\bar{r}$, truth-telling can be sustained while $\bar{r}$ is *informative*. I now show that under the new reporting system, the bank's expected payoff is higher while it is suffice to motivate high effort. Denote the bank's payoff under the existing reporting system as π_B and its payoff under the alternative reporting system as π'_B, denote the probability that r realizes as p_r, denote the loan officer's payoff under the existing reporting system as π_{Oe} and his payoff under the alternative reporting system as π'_{Oe} where e is the effort level. Notice that

$$\begin{aligned}\pi_B &\leq p_r[q\mu_r p_G(R-w_s)+(1-q)(k-w_0)]\\ &< p_r[q\frac{\mu_r}{\bar{\mu}_r}\bar{\mu}_r p_G(R-w_s)+q(1-\frac{\mu_r}{\bar{\mu}_r})(k-w_0)+(1-q)(k-w_0)]\\ &= \pi_{B'},\end{aligned}$$

so the bank's payoff is always higher under the alternative reporting system. Furthermore, I have

$$\pi_{O1}=\pi_{O0}=p_r w_0$$

as the loan officer with a high type borrower is indifferent between loan being approved or rejected, and

$$\begin{aligned}\pi'_{O1}-\pi'_{O0} =& p_r\{\frac{\mu_r}{\bar{\mu}_r}[qp_G w_s+(1-q)w_0]+(1-\frac{\mu_r}{\bar{\mu}_r})w_0\}\\ &-p_r\{\frac{\mu_r}{\bar{\mu}_r}[(q-\Delta)p_G w_s+(1-q+\Delta)w_0]+(1-\frac{\mu_r}{\bar{\mu}_r})w_0\}\\ =& p_r\frac{\mu_r}{\bar{\mu}_r}\Delta(p_G w_s-w_0)\\ >& 0,\end{aligned}$$

which implies incentive compatibility constraint for $e=1$ will still hold under the new reporting system. Hence, it must be $Pr(m=h|\theta=H)=1$ for any informative r. □

A.6 Proof of Lemma 3

Proof. I prove this lemma by contradiction. Suppose there exists a report realization r such that the bank approves a loan for H type but rejects a loan for L type, but $zp_G(R-w_s) \geq k-w_0$, which implies the bank would approve a loan for L type if it knows $\eta = G$ with certainty. We now show that such a report r is dominated by an alternative reporting strategy which perfectly reveals η.

As Proposition 1, we denote the bank's payoff under the existing reporting system as π_B and its payoff under the alternative reporting system as π'_B, denote the probability that r realizes as p_r, denote the loan officer's payoff under the existing reporting system as π_{Oe} and his payoff under the alternative reporting system as π'_{Oe} where e is the effort level.

We first show that the bank's payoff is higher under the alternative reporting system. Notice that

$$\begin{aligned}
\pi'_B - \pi_B =& p_r\{[q+(1-q)z]\mu_r p_G(R-w_s) + (1-\mu_r)(k-w_0)\} \\
& - p_r[q\mu_r p_G(R-w_s) + (1-q)(k-w_0)] \\
\geq& p_r[q\mu_r p_G(R-w_s) + (1-q)(k-w_0) + (1-\mu_r)(k-w_0)] \\
& - p_r[q\mu_r p_G(R-w_s) + (1-q)(k-w_0)] \\
>& p_r(1-\mu_r)(k-w_0) \\
>& 0,
\end{aligned}$$

so the bank's payoff is always higher under the alternative reporting system regardless of the loan officer's reporting strategy, as truth-telling maximizes the bank's payoff.

We now show that the incentive compatibility constraint still holds for the loan officer under the new reporting system. As $zp_G(R-w_s) \geq k-w_0$ but $zp_G R < k$, we must have

$zp_G w_s < w_0$. Hence, we have

$$\pi'_{O1} - \pi_{O1} = p_r\{\mu_r[q + (1-q)z]p_G w_s + (1-\mu_r)w_0\} - p_r[q\mu_r p_G w_s + (1-q)w_0]$$

and

$$\pi'_{O0} - \pi_{O0} = p_r\{\mu_r[q - \Delta + (1-q+\Delta)z]p_G w_s + (1-\mu_r)w_0\} - p_r[(q-\Delta)\mu_r p_G w_s + (1-q+\Delta)w_0],$$

which implies

$$\begin{aligned} \pi'_{O1} - \pi_{O1} - (\pi'_{O0} - \pi_{O0}) &= p_r\mu_r\Delta(1-z)p_G w_s - p_r\Delta\mu_r(p_G w_s - w_0) \\ &= p_r\Delta\mu_r(w_0 - zp_G w_s) \\ &\geq 0, \end{aligned}$$

so the incentive compatibility constraint also holds if η is perfectly revealed. By assumption, the bank approves a loan under $\eta = G$ and rejects a loan under $\eta = B$ regardless of borrowers' types. Thus truth-telling constraints for loan officer automatically hold. However, this implies that under the optimal reporting rule, there does not exist any signal realization inducing a posterior belief such that the bank's loan approval decision depends on a borrower's type θ while the loan officer is honest about it. Therefore, the bank's payoff would be the same even if the bank only uses hard information from the information system. □

A.7 Proof of Proposition 4

Proof. I prove that the optimal information system must take the form specified in the proposition by contradiction. Suppose there exists an information system with some report realization r such that $\mu_r > 0$ and $\mu_r < \min\{1, \frac{w_0}{zp_G w_s}\}$, and the loan officer would undertake $e = 1$. I construct an alternative reporting strategy such that it either reveals B state perfectly or reveals a signal r' with $\mu_{r'} = \min\{\frac{w_0}{zp_G w_s}, 1\}$ and show that the new reporting strategy dominates only reporting r.

I first check that both truth-telling constraints and loan approval constraints hold under r'. Under r', I have

$$\mu_{r'} p_G w_s > \mu_r p_G w_s \geq w_0 \tag{A.15}$$

and

$$\mu_{r'} z p_G w_s \leq \frac{w_0}{zp_G w_s} z p_G w_s = w_0, \tag{A.16}$$

which implies that truth-telling constraints are satisfied under r'. We also have

$$\mu_{r'} p_G (R - w_s) > \mu_r p_G (R - w_s) \geq k - w_0, \tag{A.17}$$

together with Lemma 3, I check that bank would approve a loan for H type but reject for L type if it sees r'.

I now verify that the bank's payoff is higher under this alternative reporting strategy and the incentive compatibility constraint for the loan officer to undertake $e = 1$ holds. I consider two cases differentiated by whether a loan is approved for an H-type borrower under r'.

Case 1: Bank approves the loan for an H-type borrower under r

I first show that the bank's payoff is higher under the alternative reporting system.

Notice that

$$\begin{aligned}\pi'_B - \pi_B =& p_r\{\frac{\mu_r}{\mu_{r'}}[q\mu_{r'}p_G(R-w_s)+(1-q)(k-w_0)]+(1-\frac{\mu_r}{\mu_{r'}})(k-w_0)\}\\ &- p_r[q\mu p_G(R-w_s)+(1-q)(k-w_0)]\\ =& p_r q(1-\frac{\mu_r}{\mu_{r'}})(k-w_0)\\ >& 0,\end{aligned}$$

so the bank's payoff is always higher under the alternative reporting system.

I now show that the incentive compatibility constraint still holds for the loan officer under the new reporting system. We have

$$\begin{aligned}\pi'_{O1} - \pi'_{O0} =& p_r\{\frac{\mu_r}{\mu_{r'}}[q\mu_{r'}p_G w_s+(1-q)w_0]+(1-\frac{\mu_r}{\mu_{r'}})w_0\}\\ &- p_r\{\frac{\mu_r}{\mu_{r'}}[(q-\Delta)\mu_{r'}p_G w_s+(1-q+\Delta)w_0]+(1-\frac{\mu_r}{\mu_{r'}})w_0\}\\ =& p_r\frac{\mu_r}{\mu_{r'}}\Delta(\mu_{r'}p_G w_s - w_0),\end{aligned}$$

and

$$\begin{aligned}\pi_{O1} - \pi_{O0} =& p_r\{[q\mu_r p_G w_s+(1-q)w_0] - p_r\{[(q-\Delta)\mu_r p_G w_s+(1-q+\Delta)w_0]\}\\ =& p_r\Delta(\mu_r p_G w_s - w_0),\end{aligned}$$

which implies

$$\pi'_{O1} - \pi'_{O0} = p_r\Delta(\mu_r p_G w_s - \frac{\mu_r}{\mu_{r'}}w_0) > \pi_{O1} - \pi_{O0}$$

as $\mu < \mu'$. Hence, the incentive compatibility constraint would hold under the alternative reporting strategy.

Case 2: Bank rejects a loan for an H-type borrower under r'

I first show that the bank's payoff is higher under the alternative reporting system. Notice that

$$\begin{aligned}\pi'_B - \pi_B =& p_r\{\frac{\mu}{\mu'}[q\mu' p_G(R-w_s) + (1-q)(k-w_0)] + (1-\frac{\mu}{\mu'})(k-w_0)\} - p_r(k-w_0)\\ =& p_r\frac{\mu}{\mu'}q[\mu' p_G(R-w_s) - (k-w_0)]\\ >& p_r\frac{\mu}{\mu'}q[\mu p_G(R-w_s) - (k-w_0)]\\ \geq& 0.\end{aligned}$$

The last inequality holds because the bank approves loans for H types after seeing r'. Therefore, the bank's payoff is always higher under the alternative reporting system.

I now show that the incentive compatibility constraint still holds under the new reporting system. We have

$$\begin{aligned}\pi'_{O1} - \pi'_{O0} =& p_r\{\frac{\mu_r}{\mu_{r'}}[q\mu_{r'} p_G w_s + (1-q)w_0] + (1-\frac{\mu_r}{\mu_{r'}})w_0\} - p_r w_0\\ =& p_r\frac{\mu_r}{\mu_{r'}}q(\mu_{r'} p_G w_s - w_0)\end{aligned}$$

and

$$\begin{aligned}\pi_{O1} - \pi_{O0} =& p_r[q\mu_r p_G w_s + (1-q)w_0] - p_r w_0\\ =& p_r q(\mu_r p_G w_s - w_0),\end{aligned}$$

which implies

$$\pi'_{O1} - \pi'_{O0} = p_r q(\mu_r p_G w_s - \frac{\mu_r}{\mu_{r'}}w_0) > \pi_{O1} - \pi_{O0}$$

as $\mu_r < \mu_{r'}$. Hence, the incentive compatibility constraint would hold under the alternative reporting strategy. □

A.8 Proof of Proposition 5

Proof. By Bayesian Plausibility, we must have $\mu_g \geq p_0$. Hence, the bank's optimization problem given a reporting system satisfying Proposition 4 could be written as:

$$\begin{aligned}
\max_{w_s, w_0} \quad & q\{\frac{p_0}{\mu_g}[\mu_g p_G(R - w_s) - k] - (1 - \frac{p_0}{\mu_g})w_0\} - (1-q)w_0 \\
\text{s.t.} \quad & q[\frac{p_0}{\mu_g}\mu_g p_G w_s + (1 - \frac{p_0}{\mu_g})w_0] + (1-q)w_0 \geq (q - \Delta)[\frac{p_0}{\mu_g}\mu_g p_G w_s + (1 - \frac{p_0}{\mu_g})w_0] + (1 - q + \Delta)w_0 + c[\lambda_1] \\
& w_s \geq 0 \quad [\lambda_2] \\
& w_0 \geq 0 \quad [\lambda_3] \\
& \mu_g p_G(R - w_s) \geq k - w_0 \quad [\lambda_4] \\
& \mu_g p_G w_s \geq w_0 \quad [\lambda_5] \\
& \mu_g z p_G w_s \leq w_0 \quad [\lambda_6].
\end{aligned}$$

The corresponding Lagrange multipliers are in square brackets. The first-order conditions after some manipulations with respect to w_s and w_0 are:

$$-qp_0p_G + \lambda_1\Delta p_0 p_G + \lambda_2 - \lambda_4\mu_g p_G + \lambda_5\mu_g p_G - \lambda_6\mu_g z p_G = 0; \tag{A.18}$$

$$q\frac{p_0}{\mu_g} - 1 - \lambda_1\Delta\frac{p_0}{\mu_g} + \lambda_3 + \lambda_4 - \lambda_5 + \lambda_6 = 0. \tag{A.19}$$

Given the non-negativity condition for w_s and w_0, we must have $w_s > 0$ because the incentive compatibility cannot hold otherwise. Thus we obtain $\lambda_2 = 0$. We must also have $w_0 > 0$ because the truth-telling constraint cannot hold for L type otherwise. Thus we obtain $\lambda_3 = 0$.

We now argue that if the program has a solution, we must have $\mu z p_G w_s = w_0$. Suppose not, then we must have $\lambda_6 = 0$, which implies (A.18) and (A.19) would be rewritten as:

$$-qp_0p_G + \lambda_1\Delta p_0 p_G - \lambda_4\mu_g p_G + \lambda_5\mu_g p_G = 0; \tag{A.20}$$

$$q\frac{p_0}{\mu_g} - 1 - \lambda_1\Delta\frac{p_0}{\mu_g} + \lambda_4 - \lambda_5 = 0. \tag{A.21}$$

It is straightforward to see that (A.20) and (A.21) cannot simultaneously hold. Hence, there is no feasible solution for this program if $\mu_g z p_G w_s < w_0$.

Now we consider $\mu_g z p_G w_s = w_0$. We must have $\lambda_6 > 0$ and $\lambda_5 = 0$ as it implies $\mu_g p_G w_s > w_0$. Now we claim $\lambda_1 > 0$. Suppose not, then manipulating (A.18) gives us

$$-qp_0 p_G - \lambda_4 \mu_g p_G - \lambda_6 \mu_g z p_G < 0, \tag{A.22}$$

which is a contradiction. Therefore, we conclude that the incentive compatibility constraint must bind. Inserting $\mu_g z p_G w_s = w_0$ into the incentive compatibility constraint gives us

$$w_s^* = \frac{c}{\Delta p_0 p_G (1-z)};$$
$$w_0^* = \frac{\mu_g z c}{\Delta p_0 (1-z)}.$$

We now check whether approving a loan for H type after seeing $r = g$ is optimal, which requires

$$\frac{\mu_g c}{\Delta p_0} \leq \mu_g p_G R - k. \tag{A.23}$$

Hence, a solution satisfying $\mu_g z p_G w_s = w_0$ exists if (A.23) holds.

From (A.23), we know that to ensure there exists at least one μ_g such that a contract inducing $e = 1$ and truth-telling is feasible, we must have

$$c \leq \bar{c} < \Delta p_0 (p_G R - k), \tag{A.24}$$

which implies that under our assumption $c \leq \bar{c}$, we can always find some μ_g such that an optimal contract satisfying $\mu_g z p w_s = w_0$ exists.

As both w_s^* and w_0^* are a function of μ_g, we can rewrite the bank's problem as selecting the optimal information system only. Define $\underline{\mu} = \max\{p_0, \frac{\Delta p_0 k}{\Delta p_0 p_G R - c}\}$, we can write the bank's optimization problem as:

$$\max_{\mu_g} \quad q\{\frac{p_0}{\mu_g}[\mu_g p_G(R - w_s^*) - k] - (1 - \frac{p_0}{\mu_g})w_0^*\} - (1 - q_0 - \Delta)w_0^*$$
$$\text{s.t.} \quad \mu_g \in [\underline{\mu}, 1].$$

The first-order condition for μ_g is:

$$\frac{qp_0 k}{\mu_g^2} - \frac{zc}{\Delta p_0(1-z)} = 0, \tag{A.25}$$

and the second-order condition for μ is

$$-\frac{2qp_0 k}{\mu_g^3} < 0. \tag{A.26}$$

Hence, we conclude that $\mu^* = p_0\sqrt{\frac{\Delta q(1-z)k}{zc}}$ if $p_0\sqrt{\frac{\Delta q(1-z)k}{zc}} \in (\underline{\mu}, 1)$, $\mu^* = \underline{\mu}$ if $p_0\sqrt{\frac{\Delta q(1-z)k}{zc}} \leq \underline{\mu}$, and $\mu^* = 1$ if $p_0\sqrt{\frac{\Delta q(1-z)k}{zc}} \geq 1$. □

A.9 Proof of Corollary 1

Proof. Define

$$F = \Delta p_0 p_G R - q\frac{p_0}{\mu^*}k + (q - \Delta)p_0 k - \frac{qc}{\Delta} - \frac{\mu^* zc}{\Delta p_0(1-z)},$$

which is reorganized from inequality (4), it is sufficient to show that F is monotonic on corresponding parameters. Given that all partial derivatives of μ^* over corresponding parameters are equal to 0 for corner solutions, and

$$\frac{qp_0 k}{\mu^{*2}} - \frac{zc}{\Delta p_0(1-z)} = 0$$

from (31) for all interior μ^*, we have the following partial derivatives:

$$\frac{\partial F}{\partial c} = \frac{qp_0k}{\mu^{*2}}\frac{\partial \mu^*}{\partial c} - \frac{q}{\Delta} - \frac{zc}{\Delta p_0(1-z)}\frac{\partial \mu^*}{\partial c} - \frac{\mu^* z}{\Delta p_0(1-z)} = -\frac{q}{\Delta} - \frac{\mu^* z}{\Delta p_0(1-z)} < 0;$$

$$\frac{\partial F}{\partial \Delta} = p_0 p_G R + \frac{qp_0k}{\mu^{*2}}\frac{\partial \mu^*}{\partial \Delta} - p_0k + \frac{qc}{\Delta^2} - \frac{zc}{\Delta p_0(1-z)}\frac{\partial \mu^*}{\partial \Delta} + \frac{\mu^* zc}{\Delta^2 p_0(1-z)} = p_0(p_G R - k) + \frac{qc}{\Delta^2} + \frac{\mu^* zc}{\Delta^2 p_0(1-z)} > 0;$$

$$\frac{\partial F}{\partial q} = \frac{qp_0k}{\mu^{*2}}\frac{\partial \mu^*}{\partial q} - \frac{p_0}{\mu^*}k + p_0k - \frac{c}{\Delta} - \frac{zc}{\Delta p_0(1-z)}\frac{\partial \mu^*}{\partial q} = -\frac{p_0}{\mu^*}k + p_0k - \frac{c}{\Delta} < 0;$$

$$\frac{\partial F}{\partial p_0} = \Delta p_G R + \frac{qp_0k}{\mu^{*2}}\frac{\partial \mu^*}{\partial p_0} - \frac{q}{\mu^*}k + (q-\Delta)k - \frac{zc}{\Delta p_0(1-z)}\frac{\partial \mu^*}{\partial p_0} + \frac{\mu^* zc}{\Delta p_0^2(1-z)} = \Delta(p_G R - k) + qk > 0;$$

$$\frac{\partial F}{\partial z} = \frac{qp_0k}{\mu^{*2}}\frac{\partial \mu^*}{\partial z} - \frac{zc}{\Delta p_0(1-z)}\frac{\partial \mu^*}{\partial z} - \frac{\mu^* c}{\Delta p_0}\frac{1}{(1-z)^2} < 0;$$

□

A.10 Proof of Corollary 2

Proof. Straightforward from equation (4.5). □

A.11 Proof of Proposition 6

Proof. Define

$$H = -q\frac{p_0}{\mu^*}k - \frac{\mu^* zc}{\Delta p_0(1-z)} + \frac{zc}{\Delta(1-z)} + p_0k - (1-q)p_0 z p_G R$$

which is reorganized from inequality (4.6), it is sufficient to show that H is monotonic on corresponding parameters. Following similar arguments from Corollary 1, we have the following partial derivatives:

$$\begin{aligned}
\frac{\partial H}{\partial c} =& -\frac{\mu^* z}{\Delta p_0(1-z)} + \frac{z}{\Delta(1-z)} \leq 0 \\
\frac{\partial H}{\partial \Delta} =& \frac{\mu^* zc}{\Delta^2 p_0(1-z)} - \frac{zc}{\Delta^2(1-z)} + p_0 z p_G R > 0 \\
\frac{\partial H}{\partial q} =& -\frac{p_0}{\mu^*}k + p_0 z p_G R < 0 \\
\frac{\partial H}{\partial p_0} =& -\frac{qk}{\mu^*} + \frac{\mu^* zc}{\Delta p_0^2(1-z)} + k - (1-q)z p_G R > 0 \\
\frac{\partial H}{\partial z} =& (1-\frac{\mu^*}{p_0})\frac{c}{\Delta(1-z)^2} - (1-q)p_0 p_G R < 0
\end{aligned}$$

□

A.12 Proof of Proposition 7

Proof. We prove this proposition by contradiction. Suppose an information system exists with some report realization r such that $\mu_r \in (0,1)$, and the loan officer would undertake $e = 1$. We show that the loan officer would be better off if η is revealed perfectly. Consider three different cases based on the equilibrium outcome of loan approval decision. As we have proved incentive compatibility constraint holds in Propositions 1 and 4, we only need to show that the loan officer's expected payoff is higher under a fully informative system.

Case 1: Only H type gets approval in equilibrium

We have

$$\begin{aligned}
\pi'_{O1} - \pi_{O1} =& p_r\{\mu_r[q + (1-q)z]p_G w_s + (1-\mu_r)w_0\} - p_r[q\mu_r p_G w_s + (1-q)w_0] \\
>& p_r\{\mu_r q p_G w_s + \mu_r(1-q)w_0 + (1-\mu_r)w_0\} - p_r[q\mu_r p_G w_s + (1-q)w_0] \\
=& p_r(1-\mu_r)q w_0 \\
\geq& 0.
\end{aligned}$$

Case 2: Both types get approval in equilibrium

We have

$$
\begin{aligned}
\pi'_{O1} - \pi_{O1} &= p_r\{\mu_r[q + (1-q)z]p_G w_s + (1-\mu_r)w_0\} - p_r\mu_r[q + (1-q)z]p_G w_s \\
&= p_r(1-\mu_r)w_0 \\
&\geq 0.
\end{aligned}
$$

Case 3: Both types get rejection in equilibrium

We have

$$
\begin{aligned}
\pi'_{O1} - \pi_{O1} &= p_r\{\mu_r[q + (1-q)z]p_G w_s + (1-\mu_r)w_0\} - p_r w_0 \\
&> p_r\{\mu_r q p_G w_s + \mu_r(1-q)w_0 + (1-\mu_r)w_0\} - p_r w_0 \\
&= p_r\mu_r q(p_G w_s - w_0) \\
&> 0.
\end{aligned}
$$

Combining these three cases, we conclude that the loan officer would be better off with a fully informative system if he undertakes $e = 1$. □

A.13 Proof of Proposition 8

Proof. By definition, an incentive compatible persuasion mechanism must satisfy following truth-telling constraints:

$$
p_{gH}\mu_{gH}p_G w_s + (1-p_{gH})w_0 \geq p_{gL}\mu_{gL}p_G w_s + (1-p_{gL})w_0; \tag{A.27}
$$

$$
p_{gL}\mu_{gL}zp_G w_s + (1-p_{gL})w_0 \geq p_{gH}\mu_{gH}zp_G w_s + (1-p_{gH})w_0. \tag{A.28}
$$

Moreover, the incentive compatibility constraints implies

$$\begin{aligned}&q[p_{gH}\mu_{gH}p_G w_s + (1-p_{gH})w_0] + (1-q)[p_{gL}\mu_{gL}zp_G w_s + (1-p_{gL})w_0]\\ \geq&(q-\Delta)[p_{gH}\mu_{gH}p_G w_s + (1-p_{gH})w_0] + (1-q+\Delta)[p_{gL}\mu_{gL}zp_G w_s + (1-p_{gL})w_0] + c,\end{aligned}$$

which implies

$$\Delta[p_{gH}\mu_{gH}p_G w_s + (1-p_{gH})w_0 - p_{gL}\mu_{gL}zp_G w_s - (1-p_{gL})w_0] \geq c. \tag{A.29}$$

We now argue that if $zp_G(R-w_s) \geq k - w_0$, the optimal persuasion mechanism satisfies $\mu_{gH} = \mu_{gL} = 1$ and $\mu_{bH} = \mu_{bL} = 0$. Similar to the arguments of Lemma 3, it is straightforward to see that bank's payoff is higher under perfect reporting system than any other alternatives, and the truth-telling constraints automatically hold. Now consider any persuasion mechanism satisfying (A.29), define $D = \Delta[p_{gH}\mu_{gH}p_G w_s + (1-p_{gH})w_0 - p_{gL}\mu_{gL}zp_G w_s - (1-p_{gL})w_0]$. Under perfect information system, incentive compatibility constraint implies

$$\Delta(1-z)p_0 p_G w_s \geq c \tag{A.30}$$

From (A.27) and (A.28), we must have $(p_{gH} - p_{gL})w_0 \geq zp_G w_s(p_{gH}\mu_{gH} - p_{gL}\mu_{gL})$. Now, define $D'\Delta(1-z)p_0 p_G w_s$, we have

$$\begin{aligned}D' - D &\propto w_s(1-z)p_0 p_G + w_s p_G[zp_{gL}\mu_{gL} - p_{gH}\mu_{gH}] + (p_{gH} - p_{gL})w_0\\ &\geq w_s(1-z)p_0 p_G + w_s p_G[zp_{gL}\mu_{gL} - p_{gH}\mu_{gH}] + zp_G w_s(p_{gH}\mu_{gH} - p_{gL}\mu_{gL})\\ &= w_s(1-z)p_G(p_0 - p_{gH}\mu_{gH})\\ &\geq 0,\end{aligned}$$

where the last inequality holds due to Bayesian Plausibility constraint for H type borrower. Therefore, we show that when $zp_G(R - w_s) \geq k - w_0$, the existence of an incentive compatible persuasion mechanism implies that a fully informative system will also be incentive compatible. As a result, when $zp_G(R - w_s) \geq k - w_0$, the optimal persuasion mechanism can always be implemented by an experiment mechanism.

When $zp_G(R - w_s) < k - w_0$, the bank would reject a loan application for any report realization if the loan officer reports $m = L$. Therefore, (A.27), (A.28), and (A.29) can be rewritten as:

$$\mu_{gH} p_G w_s \geq w_0; \tag{A.31}$$

$$\mu_{gH} z p_G w_s \leq w_0; \tag{A.32}$$

$$\Delta p_{gH}(\mu_{gH} p_G w_s - w_0) \geq c, \tag{A.33}$$

which implies when $zp_G(R - w_s) < k - w_0$, any incentive compatible persuasion mechanism is equivalent to an experiment mechanism with $\mu_{gH} = \mu_g$. □

Appendix B

Results for section 5.1.5

In this section, we formally characterize the optimal reporting system with effective communication, assuming that effort is undertaken after r is realized.

Proposition 9. *Under soft information lending, the optimal information system has two signal realizations* $\mathbb{R} = \{g, b\}$ *such that:*

- $\mu_b = 0$*;*
- $\mu_g = \min\{1, \frac{w_0}{zp_G w_s}\}$.
- *Bank approves loan if* $r = g$ *and* $m = H$ *and rejects otherwise.*

Proof. We first prove the following lemma.

Lemma 4. *If there exists an* ***informative*** *report* r*, then we must have* $zp_G(R-w_s) < k-w_0$.

Proof. We prove this lemma by contradiction. Suppose there exists a report realization r such that the bank approves a loan for H type but rejects a loan for L type, but $zp_G(R-w_s) \geq k - w_0$, which implies the bank would approve a loan for L type if it knows $\eta = G$ with certainty. We now show that such a report r is dominated by an alternative reporting strategy perfectly reveals η.

As Proposition 1, we denote the bank's payoff under the existing reporting system as π_B and its payoff under the alternative reporting system as π'_B, denote the probability that r realizes as p_r, denote the loan officer's payoff under the existing reporting system as π_{Oe} and his payoff under the alternative reporting system as π'_{Oe} where e is the effort level.

As shown in previous propositions and lemmas, it is clear that the bank is always better off with a more informative system if the loan officer is more likely to exert higher effort when the state is more likely to be good. We now show that this is indeed the case for a loan officer. As $zp_G(R - w_s) \geq k - w_0$ but $zp_G R < k$, we must have $zp_G w_s < w_0$. Hence, we have

$$\pi'_{O1} - \pi'_{O0} = p_r \mu_r [q_0 + \Delta + (1 - q_0 - \Delta)z] p_G w_s - p_r \mu_r [q_0 + (1 - q_0)z] p_G w_s$$

and

$$\pi_{O1} - \pi_{O0} = p_r [(q_0 + \Delta)\mu_r p_G w_s + (1 - q_0 - \Delta) w_0] - p_r [q_0 \mu_r p_G w_s + (1 - q_0) w_0],$$

which implies

$$\begin{aligned} \pi'_{O1} - \pi_{O1} - (\pi'_{O0} - \pi_{O0}) &= p_r \mu_r \Delta (1 - z) p_G w_s - p_r \Delta \mu_r (p_G w_s - w_0) \\ &= p_r \Delta \mu_r (w_0 - z p_G w_s) \\ &\geq 0, \end{aligned}$$

so if the loan officer exerts $e = 1$ under r, he would exert $e = 1$ under $\eta = G$. By assumption, the bank approves loans for both types of borrowers under $\eta = G$ and rejects loans for both types of borrowers under $\eta = B$. Thus truth-telling constraints for the loan officer automatically hold. However, this implies that under the optimal reporting rule, there is no signal realization inducing a posterior belief such that the bank's loan approval decision depends on the borrower's type θ while the loan officer is honest about it. Therefore, the bank's payoff would be the same even if the bank only uses hard information from the information system. □

We now prove that the optimal information system must take the form specified in the proposition by contradiction. Suppose there exists an information system with some report realization r such that $\mu_r > 0$ and $\mu_r < \min\{1, \frac{w_0}{zp_G w_s}\}$, and the loan officer would undertake $e = 1$. We construct an alternative reporting strategy such that it either reveals B state perfectly or reveals a signal r' with $\mu_{r'} = \min\{\frac{w_0}{zp_G w_s}, 1\}$ and show that the new reporting strategy dominates only reporting r. Similar to previous propositions and lemmas, the truth-telling constraints and loan approval constraints hold under r', and the bank's payoff would always be higher if providing more information does not weaken a loan officer's incentive to undertake efforts. We only need to verify if this is the case for the loan officer. If a loan is rejected under r regardless of θ, then it is obvious that the loan officer would undertake $e = 0$ after seeing r. If loans are approved for H type borrowers under r, then the result directly follows Proposition 4. □

We now move on to jointly determine the optimal signal structure and contract.

Proposition 10. *Under soft information lending, if e is exerted after r is realized, then the optimal compensation satisfies $w_s^* = \frac{c}{\Delta p_G(1-z)}$ and $w_0^* = \frac{zc}{\Delta(1-z)}$ which implies $\mu_g^* = 1$.*

Proof. By Bayesian Plausibility, we must have $\mu_g \geq p_0$. Hence, the bank's optimization problem given a reporting system satisfying Proposition 4 could be written as:

$$
\begin{aligned}
\max_{w_s, w_0} \quad & \frac{p_0}{\mu_g}\{[(q_0+\Delta)\mu_g p_G(R-w_s)-k]-(1-q_0-\Delta)w_0\}-(1-\frac{p_0}{\mu_g})w_0 \\
\text{s.t.} \quad & (q_0+\Delta)\mu_g p_G w_s+(1-q_0-\Delta)w_0 \geq q_0\mu_g p_G w_s+(1-q_0)w_0+c \quad [\lambda_1] \\
& w_s \geq 0 \quad [\lambda_2] \\
& w_0 \geq 0 \quad [\lambda_3] \\
& \mu_g p_G(R-w_s) \geq k-w_0 \quad [\lambda_4] \\
& \mu_g p_G w_s \geq w_0 \quad [\lambda_5] \\
& \mu_g z p_G w_s \leq w_0 \quad [\lambda_6].
\end{aligned}
$$

The corresponding Lagrange multipliers are in square brackets. The first-order conditions after some manipulations with respect to w_s and w_0 are:

$$-(q_0+\Delta)p_0p_G+\lambda_1\Delta\mu_g p_G+\lambda_2-\lambda_4\mu_g p_G+\lambda_5\mu_g p_G-\lambda_6\mu_g z p_G=0; \tag{B.1}$$

$$(q_0+\Delta)\frac{p_0}{\mu_g}-1-\lambda_1\Delta+\lambda_3+\lambda_4-\lambda_5+\lambda_6=0. \tag{B.2}$$

Given the non-negativity condition for w_s and w_0, we must have $w_s > 0$ because the incentive compatibility cannot hold otherwise. Thus we obtain $\lambda_2 = 0$. We must also have $w_0 > 0$ because the truth-telling constraint cannot hold for L type otherwise. Thus we obtain $\lambda_3 = 0$.

We now argue that if the program has a solution, we must have $\mu_g z p_G w_s = w_0$. Suppose not, then we must have $\lambda_6 = 0$, which implies (B.1) and (B.2) would be rewritten as:

$$-(q_0+\Delta)p_0p_G+\lambda_1\Delta\mu_g p_G-\lambda_4\mu_g p_G+\lambda_5\mu_g p_G=0; \tag{B.3}$$

$$(q_0+\Delta)\frac{p_0}{\mu_g}-1-\lambda_1\Delta+\lambda_4-\lambda_5=0. \tag{B.4}$$

It is straightforward to see that (B.3) and (B.4) cannot simultaneously hold. Hence, there is no feasible solution for this program if $\mu_g z p_G w_s < w_0$.

Now we consider $\mu_g z p_G w_s = w_0$. We must have $\lambda_6 > 0$ and $\lambda_5 = 0$ as it implies $\mu_g p_G w_s > w_0$. Now we claim $\lambda_1 > 0$. Suppose not, then manipulating (B.1) gives us

$$-(q_0 + \Delta)p_0 p_G - \lambda_4 \mu_g p_G - \lambda_6 \mu_g z p_G < 0, \tag{B.5}$$

which is a contradiction. Therefore, we conclude that the incentive compatibility constraint must bind. Inserting $\mu_g z p_G w_s = w_0$ into the incentive compatibility constraint gives us

$$w_s^* = \frac{c}{\Delta \mu_g p_G (1-z)};$$
$$w_0^* = \frac{zc}{\Delta(1-z)}.$$

We now check whether it is optimal to approve loans for H types after seeing $r = g$, which requires

$$\frac{c}{\Delta} \leq \mu_g p_G R - k. \tag{B.6}$$

Hence, a solution satisfying $\mu z p_G w_s = w_0$ exists if (B.6) holds.

As both w_s^* and w_0^* are a function of μ_g, we can rewrite the bank's problem as selecting the optimal information system only. From Proposition 4, we know we can always find some μ_g such that there exists an optimal contract such that $\mu_g z p w_s = w_0$. Define $\underline{\mu} = \max\{p_0, \frac{\Delta p_0 k}{\Delta p_0 p_G R - c}\}$, we can write the bank's optimization problem as:

$$\max_{\mu_g} \quad (q_0 + \Delta)\{\frac{p_0}{\mu_g}[\mu_g p_G (R - w_s^*) - k] - (1 - \frac{p_0}{\mu_g}) w_0^*\} - (1 - q_0 - \Delta) w_0^*$$
$$\text{s.t.} \quad \mu_g \in [\underline{\mu}, 1].$$

The first-order condition for μ is:

$$\frac{(q_0+\Delta)p_0 c}{\Delta\mu_g^2} + \frac{(q_0+\Delta)p_0 k}{\mu_g^2} > 0. \tag{B.7}$$

Thus, we conclude that $\mu_g^* = 1$. □