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Transparency and collateral: central versus bilateral clearing*

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Abstract

Bilateral financial contracts typically require an assessment of counterparty risk. Central clearing of these financial contracts allows market participants to mutualize their counterparty risk, but this insurance may weaken incentives to acquire and to reveal information about such risk. When considering this trade-off, participants would choose central clearing if information acquisition is incentive compatible. If it is not, they may prefer bilateral clearing, when this choice prevents strategic default while economizing on costly collateral. In either case, participants independently choose the efficient clearing arrangement. Consequently, central clearing can be socially inefficient under certain circumstances. These results stand in contrast to those in Acharya and Bisin (2014), who find that central clearing is always the optimal clearing arrangement.

Keywords: Limited commitment, central counterparties, collateral

JEL classification: G10, G14, G20, G23

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1 Introduction

Two important aspects characterize modern financial contracting. One is that financial institutions trade a variety of products bilaterally, such as over-the-counter (OTC) derivatives, repurchase agreements, and reserves held at the central bank.¹ The second is the difficulty in evaluating the risk that a counterparty will not fulfill its future obligations. To mitigate this risk by appropriately choosing contractual terms, such as prices and collateral, information about the exposure of a counterparty to various risks is necessary. This information, however, often lays within the walls of a bilateral relationship due to the high degree of specialization in understanding and pricing risks specific not only to a certain financial product, but to the interaction between the counterparties across other financial markets.

The recent financial crisis has highlighted the systemic importance of this information.² Both academic researchers and policy makers argued that during the crisis asymmetric information and lack of transparency in over-the-counter markets contributed to uncertainty over the risks that certain institutions posed, causing runs and exacerbating financial distress.³ Consequently, particular attention has been devoted to the role of clearing institutions and to their potential in improving transparency in financial markets.⁴ Mandatory clearing via a central counterparty (CCP), defined below, has been at the center of financial reforms both in the US and in Europe. However, the consequences of these reforms on the incentives of financial market participants to acquire information about each other are not well understood.

In this paper, we address the question of potential tradeoffs between bilateral and central clearing with respect to market transparency. We develop a model where information about a counterparty is *soft* in the sense that it can be verified only by agents within the bilateral transaction. This assumption captures the idea that soft information is often related to

¹See Krishnamurthy et al. (2014), http://www.newyorkfed.org/banking/tpr_infr_reform_data.html (2014), <http://www.newyorkfed.org/markets/glds/search.html> (2014); and for the Federal Funds market Afonso and Lagos (2012a), Afonso and Lagos (2012b), Bech and Atalay (2010).

²Among many, see Caballero and Simsek (2009), Zawadowski (2011), and Zawadowski (2013).

³See Acharya and Bisin (2014), Pirrong (2009), and Powell (November, 21st 2013), Duffie et al. (2010), Jackson and Miller (2013).

⁴See Acharya and Bisin (2014) on transparency, but also Biais et al. (2016), and Koepl (2012) among others.

significant synergies across different projects and trades which are observable only to the agents involved in such a class of activities. Thus, soft information cannot be easily and publicly verified by a third party, or it is difficult to summarize and aggregate.⁵

In our economy, clearing arrangements affect equilibrium outcomes, including incentives to acquire information about counterparties. Trading is bilateral and subject to two frictions: limited pledgeability of a counterparty's future income, and private information about the degree of pledgeability of income. Costly monitoring reveals the extent to which a counterparty's income is pledgeable. This information, however, is not available to a third party, such as a clearing institution, which has to induce truthful reporting about the monitoring activity and its outcome by choosing contractual terms appropriately. When monitoring does not take place, counterparty pledgeability types cannot be part of contractual terms, and pooling contracts are the only feasible contracts. In this case, information is not available to financial market participants, and in particular to clearing institutions; such lack of information may disrupt the provision of central clearing services.

Because different clearing arrangements provide different incentives, the optimal clearing arrangement depends on the structure of financial assets traded and the information set of market participants. The choice of clearing arrangement is always constrained Pareto optimal, and as a consequence any restriction on the contract traded or on the clearing arrangement reduces welfare, despite the absence of externalities or systemic risk considerations. Our model is novel in this respect: it shows that crucial information acquired in a bilateral relationship may be lost when clearing services are transferred to a central counterparty, and it shows what characteristics of assets and trades are more likely to be associated with bilateral and central clearing arrangements.

Clearing is the process of transmitting, reconciling and confirming payment orders or instructions to transfer securities prior to settlement. Clearing is bilateral when it takes place via traders' respective clearing banks: under this arrangement each trader bears the risk that her bilateral counterparty may default. Traders manage this risk by requiring collateral to be

⁵See Stein (2002), Petersen (2004), Hauswald and Marquez (2006), Mian (2003).

posted. Central clearing is done by a third party, namely a central counterparty (CCP), that transforms the nature of the risk exposure of the two parties in a trade. A CCP is an entity that interposes itself between two counterparties, becoming the buyer to every seller and the seller to every buyer for the specified set of contracts.⁶

The substitution of the CCP as the sole counterparty for each of the two original traders in a bilateral exchange is called novation. Through novation of the original contract, the CCP observes *all* contracts traded by institutions for which it performs clearing services in a *specified* financial market. Both *all* and *specified* are important components of this definition: the first one implies that, within a specific market, the CCP has information about the network of trades across its members, which may not be available to the bilateral counterparties. The second implies that the CCP may lack information about its members, if that information is learned outside the specified set of contracts which the CCP clears, such as *soft* information. Previous research on CCPs, for example Acharya and Bisin (2014), has focused on the first component, recognizing the potential welfare benefits of CCP clearing. Instead, we focus on the second component and characterize the conditions under which CCP clearing might reduce welfare relative to bilateral clearing.

The tradeoff between bilateral and central clearing arises from *i*) two dimensions of risk against which traders value insurance, namely uncertain counterparty's income and pledgeability type, and *ii*) private information about a counterparty's pledgeability type, which introduces an adverse selection problem.

The severity of the adverse selection problem interacts with the value of insurance in different ways in each clearing arrangement. With bilateral clearing, counterparty risk is managed through collateral requirements, which are costly in terms of foregone investment opportunities. Costly monitoring provides the information about the counterparty's income necessary to tailor collateral requirements to the counterparty's pledgeability type.

With CCP clearing, uncertainty about a counterparty's income is managed through loss mutualisation across members, as in Acharya and Bisin (2014), Koepl and Monnet (2010),

⁶See Capital requirements for bank exposures to central counterparties and BIS glossary of terms used in payments and settlement systems, 2003.

and Biais et al. (2016). Loss mutualisation enables the CCP to diversify counterparty risk and save on collateral requirements. However, the ability of the CCP to pool risk across its members interacts in an important way with the supply of information about pledgeability types. When the CCP can induce each member to monitor a counterparty and truthfully reveal her type, it can implement separating contracts that make central clearing Pareto superior to bilateral clearing. We call an allocation that satisfies these conditions incentive-feasible.⁷

When incentive feasible allocations do not exist, there is a trade-off between bilateral and central clearing. CCP clearing naturally maintains the ability to provide insurance by pooling risk over idiosyncratic shocks to income.

Without the information generated by monitoring, however, the CCP cannot tailor contracts to the quality of the counterparties in a trade, resulting in either excessive or insufficient collateral. With bilateral clearing only insurance via collateral requirements is feasible. This is costly, but it is exactly this cost that preserves incentives to monitor. Intuitively, monitoring produces information useful in customizing collateral requirements to the type of counterparty and, when collateral is costly, this information is very valuable. If monitoring is not too costly, traders prefer bilateral clearing. The insurance provided by the CCP is not sufficient to compensate for the loss of information about a counterparty's type. Note that this result is not related to the common idea that CCPs may generate moral hazard and increase risk by providing insurance. In our economy the amount of risk is fixed. Rather, it is due to the lack of incentives to acquire and transmit information about counterparties, which may result from the activity of the CCP.

Related to the trade-off we analyze, certain practitioners and analysts have expressed concerns about recent reforms of clearing arrangements. Gregory (2014), Section 1.5, discusses possible dangers of introducing mandatory central counterparty clearing: "A third potential problem [of CCP clearing] is related to loss mutualization that CCPs use whereby any losses in excess of a member's own financial resources are generally mutualized across all the surviving

⁷Because monitoring and truth-telling are incentive feasible, then the CCP tailors collateral requirements to counterparty types, and is able to implement transfers that make every participant better off.

members. The impact of such mechanism is to homogenize the underlying credit risk such that all CCP members are more or less equal. . . . Many firms trading derivatives (e.g. large banks and hedge funds) specialize precisely in understanding risks and pricing, and hence are likely to have better information than CCPs especially for more complex derivatives.” Indeed, “One of the last futures exchanges to adopt a CCP was the London Metal Exchange in 1986 (again with regulatory pressure being a key factor).” (Gregory (2014), Section 2.1.5.)

The results and assumptions of our model are moreover consistent with the empirical evidence in Bignon and Vuillemeys (2016). First, we assume that the CCP cannot directly monitor ultimate investors. Bignon and Vuillemeys (2016) find evidence of this information asymmetry in the failure of the *Caisse de Liquidation des Affaires et Marchandises* (CLAM, a CCP clearing sugar futures) in Paris in 1974, as *retail investors were unsophisticated and non-diversified, did not have enough liquid financial resources* and that CLAM could not *directly monitor ultimate investors*.⁸ Second, we show the existence of equilibria where lenders do not have incentives to acquire information about their counterparties and/or pass it on to the CCP. In equilibrium, then, the CCP is unable to charge member-specific margins. Bignon and Vuillemeys (2016) show that CLAM kept margins *at a constant level across members*, which *was not sufficient to ensure stable clearing* and ended with the failure of a large CCP member and eventually of the CCP itself.

The paper is organized as follows: the remainder of this section provides a literature review, Section 2 describes the model, Sections 3 and 4 characterize the contract with bilateral and central clearing respectively, and Section 5 characterizes the optimal contract and clearing arrangement chosen by traders. Section 6 concludes.

1.1 Related Literature

Our paper relates to the literature that studies how changes in financial market infrastructure influence the exposure of market participants to default as well as market liquidity risk.

Part of this literature has focused on the benefits of CCP clearing. Carapella and Mills

⁸Bignon and Vuillemeys (2016) go even further, theorizing *risk-shifting* behavior on the part of the CCP once it realized it was close to bankruptcy.

(2011) focus on netting and highlight a liquidity enhancing role for CCPs, which reduce trading costs and facilitate socially desirable transactions that would not occur with bilateral clearing. Koepl and Monnet (2010) focus on novation and counterparty risk insurance: in their framework CCP clearing is the efficient arrangement for centralized trading platforms, and it improves on bilateral clearing for OTC trades by providing a better allocation of default risk. Acharya and Bisin (2014) focus on information dissemination and stress the welfare enhancing effect of central clearing on transparency: CCP clearing can correct for an externality introduced by the non-observability of trading positions, when the exposure to third parties can cause a counterparty to default. Monnet and Nellen (2012) focus on two-sided limited commitment and show that a CCP can improve on a segregation technology (defined as a vault for collateral assets) through novation and mutualization.

We differ from these papers as in our model the provision of clearing services by a CCP is endogenously limited, and central clearing may not be desirable. Duffie and Zhu (2011) also show that introducing a CCP that clears a class of derivatives may lead to an increase in average exposure to counterparty default. However, their mechanism is very different from ours, as their focus is on netting. The authors show that when a CCP is dedicated to clear only one class of derivatives, the benefits of bilateral netting between pairs of counterparties across different assets may be larger than the benefits of multilateral netting among many clearing participants but within a single class of assets. In our model, we focus on novation and mutualization of losses as the key features of central clearing.

In this respect, our paper is closer to Koepl (2012), Biais et al. (2012), and Biais et al. (2016). In these papers moral hazard limits the provision of insurance. Biais et al. (2012) and Biais et al. (2016) show that central clearing can provide insurance against counterparty risk, but must be designed to preserve risk-prevention incentives. As a result traders end up bearing some of their idiosyncratic risk. Koepl (2012) considers an environment with moral hazard, where collateral can serve either as an incentive device or as an insurance device. When a CCP cannot observe the degree of moral hazard and opts to use collateral as an incentive device, central clearing can have the unintended consequence of forcing collateral

to increase for all contracts, reducing market liquidity, and adversely affecting market discipline. In our environment the CCP provides insurance via loss mutualisation as well, but, via novation, it interacts with adverse selection and costly monitoring. This interaction affects traders' incentives to acquire socially valuable information about their trading partners, and transmit it to the CCP. This mechanism is similar to what Pirrong (2009) suggests: information asymmetries between the CCP and its clearing members may result in an increase in counterparty risk at the CCP, especially for complex products traded by large and opaque financial institutions.

Our paper is also related to the literature on payment systems, in particular to Koepl et al. (2012), who study the efficiency of a clearing and settlement system in an environment with information asymmetry between the clearing institution and traders. In our model, trading is subject to an information asymmetry as well: traders can costly acquire soft information about their counterparty while the clearing institution cannot. However, the focus of our paper is the endogenous effect of this information asymmetry on the credit risk faced by the clearing institution. In this respect our paper complements the one by Koepl et al. (2012) by characterizing how central clearing can affect transparency and risk management in financial markets.

Finally, it is worth highlighting that both our results and the economic mechanism at the core of our analysis are consistent with some empirical findings on central clearing for credit default swaps. Although they cannot measure monitoring and transparency directly, Loon and Zhong (2014) find that trading volume increase when credit default swaps are cleared centrally. This is an equilibrium outcome of our model, despite transparency may decrease with central clearing.

2 The Model

Time is discrete and consists of two periods, $t = 1, 2$. The economy is populated by two types of agents: a unit measure of *lenders* and a unit measure of *borrowers*. Lenders and borrowers have different preferences, and have access to different technologies.

There are two goods: a consumption good and a capital good. The capital good can be invested at time $t = 1$ and transformed with a linear technology into time $t = 2$ consumption. Only borrowers have access to this technology. The technology is indivisible, takes one unit of capital good at $t = 1$, and returns $\tilde{\theta}$ units of consumption good at $t = 2$; $\tilde{\theta}$ is a random variable with support $\{0, \theta\}$, whose realization is unknown at the time of investment. We define $p = \text{Prob}(\tilde{\theta} = \theta)$ to be the probability of success of investment.

In the first period, lenders receive an endowment of one unit of capital, while borrowers receive an endowment of ω units of consumption good. The consumption good can be stored from $t = 1$ to $t = 2$ by both lenders and borrowers.

Borrowers have preferences biased towards consumption in the first period relative to lenders. Specifically, borrowers' preferences are defined over $t = 1$ consumption c_1 and time $t = 2$ consumption c_2 , and are represented by the utility function

$$U(c_1, c_2) = \alpha c_1 + c_2 \quad \alpha > 1$$

Borrowers have limited commitment to repay: a borrower can repudiate a contract and, after default, consume a fraction $1 - \lambda^i$ of the output realization. There are two types of borrowers, distinguished by the extent to which they can pledge their income. A measure q of borrowers can pledge a fraction λ^H of their income, and a measure $1 - q$ can pledge a fraction λ^L , where $\lambda^H > \lambda^L$. The type λ^i is private information of the borrower, but can be learned by a lender before trading by exerting monitoring effort.

The preferences of a lender are defined over second period consumption x_2 , and time-1 monitoring effort e , according to the utility function

$$V(x_2, e) = u(x_2) - \gamma \cdot e$$

where u is strictly increasing and strictly concave, and $e \in \{0, 1\}$. We further assume that $\lim_{x \rightarrow 0} u'(x) = +\infty$.

The mismatch between endowments and preferences over consumption goods generates

incentives to trade: lenders have capital but they need borrowers to use their technology to transform it into consumption goods. Nevertheless, trade is subject to two frictions. First, there is limited commitment; second, each lender is randomly matched and can only contract with one borrower. Trade is bilateral.

When a lender and a borrower are matched with each other, they enter into a relationship described by a contract. The lender provides the contract to the borrower as a take-it-or-leave-it (TIOLI) offer, which also specifies a clearing and settlement arrangement.⁹

In the second period, settlement takes place either bilaterally or through a CCP, according to the lenders' choice. Feasible contracts differ depending on the clearing arrangement initially chosen. In the next sections, we define and characterize optimal contracts with bilateral and central clearing.

Labeling agents as *lenders* and *borrowers*, and modeling the contract between them as a loan is meant to capture the counterparty (credit) risk of a financial relationship. In this respect, it should not be thought of as a restriction on the set of contracts analyzed in our model relative to the set of contracts which are bilaterally and centrally cleared in reality. A loan in our model is the analog of any financial obligation with a component of counterparty risk, which we formalize as limited commitment to honor such obligation. Whether the obligation is a repayment for a loan obtained in the past –as in a repurchase agreement or a bond– or the transfer of an asset –as in an option which is exercised by its holder– the limited commitment to keep promises previously made is intrinsically the same. Limited commitment is the pivotal friction in the model, and it introduces interesting interactions between the clearing arrangement, the terms of the contract traded, and the information acquired about the counterparty.

⁹When the commitment constraint is binding, the assumption of a TIOLI is without loss of generality because of transferable utility.

3 Contracts with bilateral clearing

When a lender and a borrower are matched at the beginning of $t = 1$, the lender chooses whether or not to verify her counterparty type by exerting effort, a decision denoted respectively by $e = 1$ and $e = 0$.

If $e = 1$, the lender learns her counterparty type λ^i , $i \in \{L, H\}$. The lender then can offer a contract that prevents the borrower from defaulting strategically in equilibrium. Therefore, a contract with bilateral clearing and monitoring is a list $(x_{2,h}^i, x_{2,l}^i, c_1^i, c_{2,h}^i, c_{2,l}^i)$, where $x_{t,s}^i$ and $c_{t,s}^i$ are respectively the lender's and the borrower's consumption in time t and state s , when the borrower's type is i . The contract is indexed by the borrower's type i , and second-period consumption is indexed by the idiosyncratic state $s \in \{l, h\}$. If the borrower accepts the contract, the lender transfers the unit of capital to the borrower, and the borrower transfers $\omega - c_1^i$ units of consumption good to the lender. We can think of the transfer $\omega - c_1^i$ as collateral as it denotes the amount of consumption good stored by the lender to be consumed at $t = 2$. In this respect $\omega - c_1^i$ is akin to margins in financial transactions (or a house in a mortgage) as it preserves the value of the lender's investment by insuring the lender against the borrower's default.¹⁰ The borrower then chooses to invest the unit of capital, while the lender chooses to store the consumption good $\omega - c_1^i$. In the second period, the borrower is entitled to consumption $c_{2,s}^i$, whereas the lender is entitled to $x_{2,s}^i$.

Differently, if $e = 0$, the lender does not verify the counterparty's type, which remains private information of the borrower. In this circumstance, the lender commits to a mechanism that specifies a menu of contracts. Without loss of generality, we assume that the lender commits to direct revelation mechanisms, that is, a contract is executed after the borrower truthfully announces her type. However, since type i is private information, we cannot conclude, as in the previous paragraph, that the contracts offered by the lender will always prevent borrowers from defaulting in equilibrium. In other words, default may not be just an off-equilibrium event, and it is necessary that we specify contracts to account for this possibil-

¹⁰Notice that we are assuming one sided limited commitment, only on the side of the borrower. Therefore lenders always return the collateral to borrowers if $\tilde{\theta} = \theta$. Storage is verifiable.

ity. Formally, a strategy for a borrower is a pair $(m^i, \sigma^i) \in \{\lambda^L, \lambda^H\} \times \{0, 1\}$, where m^i is the reporting strategy and σ^i is the default strategy: $\sigma^i = 1$ means that the borrower defaults in equilibrium. A mechanism is a list of contracts $(\Sigma^i, x_{2,h}^i, x_{2,l}^i, c_1^i, c_{2,h}^i, c_{2,l}^i)_{i \in \{L,H\}}$, where Σ^i is the lender's default recommendation (contingent to the idiosyncratic state $s = h$) to a borrower that reports her type to be λ^i . $\Sigma^i = 1$ means that the lender recommends the borrower to default in equilibrium. Δ represents the public history of the borrower's default/repayment decision. $\Delta = 1$ if the borrower defaults in equilibrium, and $\Delta = 0$ if the borrower repays. We say that a contract is incentive-compatible if a borrower's best strategy (m^i, σ^i) is to report truthfully her type, $m^i = \lambda^i$, and then follow the default/repayment recommendation, $\sigma^i = \Sigma^i$. The timing is similar to the case with monitoring: after reporting the type and accepting the ensuing contract, the borrower receives one unit of capital and transfers $\omega - c_1^i$ units of consumption good to the lender. In the second period, after the shock realization is known, the borrower chooses whether to default ($\sigma^i = 1$) or to repay ($\sigma^i = 0$). In case of repayment, the borrower is entitled to consumption $c_{2,s}^i$, and the lender to consumption $x_{2,s}^i$. In case of default, the borrower's consumption is equal to $(1 - \lambda^i)\theta$, while the lender is left with $\lambda^i\theta + \omega - c_1^i$.

3.1 The contract with information acquisition

Lenders matched with a λ^H borrower solve a similar problem to the one that lenders matched with λ^L borrowers face, with λ^L replaced by λ^H .

Let V_i denote the value to a lender of a match with a borrower of type λ^i , once the lender has paid the cost γ and knows the borrower's type. Then lenders choose contracts $(x_{2,h}^i, x_{2,l}^i, c_1^i, c_{2,h}^i, c_{2,l}^i)_{i \in \{L,H\}}$ to solve

$$(P^i) \quad V_i = \max_{(x_{2,h}^i, x_{2,l}^i, c_1^i, c_{2,h}^i, c_{2,l}^i) \in \mathbb{R}_+^5} pu(x_{2,h}^i) + (1-p)u(x_{2,l}^i) - \gamma \quad (1)$$

$$s.t. \quad \alpha c_1^i + pc_{2,h}^i + (1-p)c_{2,l}^i \geq \alpha\omega \quad (2)$$

$$\omega \geq c_1^i \geq 0 \quad (3)$$

$$c_{2,h}^i + x_{2,h}^i \leq \omega - c_1^i + \theta \quad (4)$$

$$c_{2,l}^i + x_{2,l}^i \leq w - c_1^i \quad (5)$$

$$c_{2,h}^i \geq (1 - \lambda^i)\theta \quad (6)$$

Constraint (2) is the borrower's participation constraint: the borrower can always refuse to trade, and consume the endowment ω in the first period. Constraint (3) is time $t = 1$ feasibility of the consumption plan, and likewise (4) and (5) are time $t = 2$ feasibility in states h and l respectively. Constraint (6) is the borrower's individual rationality constraint: the borrower can default and consume $1 - \lambda^i$ units of consumption (in the low state $\tilde{\theta} = 0$, and the limited commitment to repay is not relevant).

It is easy to see that at a solution both second-period feasibility constraints (4) and (5) should bind. Solving for $x_{2,h}^i$ and $x_{2,l}^i$ and replacing their values in the objective function (1), we can solve for $(c_1^i, c_{2,h}^i, c_{2,l}^i)$.

Because $\alpha > 1$, a lender's expected consumption is larger when the borrower consumes her whole endowment ω in $t = 1$, and nothing in $t = 2$. However, such a contract violates the individual rationality constraint (6), and leaves the lender with no consumption in the second period when the output realization is low, as implied by constraint (5). Therefore, the lender will always store some of the borrower's endowment from time $t = 1$ to time $t = 2$. Collateral then plays two roles. First, it provides insurance to the lender against the risk of the low-consumption state at $t = 2$ when $s = l$. Second, it provides the borrower incentives to repay at $t = 2$. It does so indirectly, by storing consumption goods up to $t = 2$. The larger this amount, the easier it is for the borrower to satisfy the limited commitment constraint (6).

Lemma 1 *With bilateral clearing, if the lender pays the monitoring cost γ then i) $c_1^i < \omega$, ii) $c_{2,l}^i = 0$ and $x_{2,h}^i > x_{2,l}^i$.*

Lemma 1 implies that the solution to the contract with bilateral clearing is such that i) collateral is always positive, and ii) insurance is incomplete. Counterparty risk, the risk that the counterparty may be unable or unwilling to settle her obligations, is managed by

requiring collateral to be posted. The collateral requirement $\omega - c_1^i$ insures against this risk. However collateral must be used efficiently, since it is costly. Therefore $c_{2,l}^i = 0$ and insurance is incomplete.

First, consider the case when the collateral endowment ω is scarce relative to the counterparty type λ^i , namely $\omega \leq \omega(\lambda^i) \equiv \frac{(1-\lambda^i)p\theta}{\alpha}$. Then, in the next lemma we show that the scarcity of collateral provides the borrower with some additional rents relative to her outside option, even though the optimal contract asks the borrower to post all the available collateral in $t = 1$.

Lemma 2 *If $\omega < \frac{(1-\lambda^i)p\theta}{\alpha}$, the participation constraint (2) is slack. In addition, the limited commitment constraint (6) is binding and $c_1 = 0$. This is area 4 in Figure 1.*

Next, consider the case when $\omega > \frac{(1-\lambda^i)p\theta}{\alpha}$. Let μ and η be the multipliers associated with (2) and (6) respectively. The first order conditions for optimality are

$$-pu'(\omega - c_1^i + \theta - c_{2,h}^i) + p\mu + \eta = 0 \quad (7)$$

$$-pu'(\omega - c_1^i + \theta - c_{2,h}^i) - (1-p)u'(\omega - c_1^i) + \alpha\mu \leq 0 \quad (8)$$

with equality if $c_1^i > 0$. Together with the complementary slackness conditions

$$\mu\{\alpha c_1^i + pc_{2,h}^i - \alpha\omega\} = 0 \quad (9)$$

and

$$\eta\{c_{2,h}^i - (1-\lambda^i)\theta\} = 0 \quad (10)$$

they fully characterize the solution to the problem. Let λ^* be the unique value satisfying

$$\frac{\alpha - p}{1 - p} = \frac{u' \left(\frac{(1-\lambda^*)p\theta}{\alpha} \right)}{u' \left(\theta - \frac{\alpha-p}{\alpha}(1-\lambda^*)\theta \right)} \quad (11)$$

Intuitively, λ^* is the smallest value of λ such that the limited commitment constraint is slack. For any $\lambda \leq \lambda^*$, the limited commitment constraint (6) is binding because the quality

of the counterparty is relatively low, which is equivalent to a high borrower's temptation to default.

Lemma 3 *With bilateral clearing, if the lender pays the cost γ to monitor the borrower and $\omega > \frac{(1-\lambda^i)p\theta}{\alpha}$, then the participation constraint (2) binds. Moreover,*

a) *If $\lambda^i < \lambda^*$, then $c_{2,h}^i = (1 - \lambda^i)\theta$ and $c_1^i = \omega - \frac{(1-\lambda^i)p\theta}{\alpha}$.*

b) *If $\lambda^i > \lambda^*$, and $\omega < \frac{(1-\lambda^*)p\theta}{\alpha}$, then $c_{2,h}^i = \frac{\alpha\omega}{p} > (1 - \lambda^i)\theta$ and $c_1^i = 0$.*

c) *If $\lambda^i > \lambda^*$, and $\omega \geq \frac{(1-\lambda^*)p\theta}{\alpha}$, then $c_1^i = \omega - \frac{(1-\lambda^*)p\theta}{\alpha}$ and $c_{2,h}^i = (1 - \lambda^*)\theta > (1 - \lambda^i)\theta$.*

The solution to the problem (P^i) is shown in Figure 1. The partition of the state space depends on two key parameters: the borrower's endowment, ω , and the borrower's type λ^i , which indicates the borrower's quality. The interaction of the two determines whether both the limited commitment and the participation constraint bind, or only one of them binds.

The temptation to default $1 - \lambda^i$ measures the severity of the commitment problem, so that when λ^i is relatively low the borrower has relatively high incentive to default, the solution to (P^i) must be such that the limited commitment constraint binds.

We can then distinguish two scenarios: when ω is relatively low ($\omega \leq \frac{(1-\lambda^i)p\theta}{\alpha}$), the scarcity of collateral limits the possibility of using it to provide incentives to repay, and the borrower earns some rents for this reason.¹¹ The participation constraint is slack and the limited commitment constraint binds. Finally, because ω is relatively scarce, $c_1 = 0$. This solution is described in area 4 in Figure 1.

When ω is relatively high, the participation constraint binds: this is true for solutions a, b, c in Lemma 3, which correspond to areas 1, 2, 3 in Figure 1. Whether the limited commitment constraint binds¹² or not¹³ depends on the severity of the commitment problem with respect to λ^* : if $\lambda^i \leq \lambda^*$ then the borrower's temptation to default is strong, and the limited commitment constraint binds.

¹¹Because ω is low, any allocation satisfying the (2) at equality would violate the limited commitment constraint (6). In this sense, in order to give incentives to the borrower to repay at $t = 2$, her utility is larger than her outside option $\alpha\omega$, despite the lender makes a TIOLI offer.

¹²Solution 2a and area 3 in Figure 1.

¹³Solutions 2b, 2c and areas 1, 2 in Figure 1.

If $\lambda^i > \lambda^*$ then the borrower's temptation to default is low, so the limited commitment constraint is slack. In this case, the more important role of collateral is the insurance against the low realization of $\tilde{\theta}$. Let $\frac{(1-\lambda^*)p\theta}{\alpha}$, for λ^* solving (11), be the level of collateral that provides the lender with the efficient level of insurance. Thus, we can distinguish two sub-cases: the first, ($\omega \leq \frac{(1-\lambda^*)p\theta}{\alpha}$), in which the scarcity of collateral does not allow for the efficient provision of insurance, and $c_1^i = 0$; the second, ($\omega > \frac{(1-\lambda^*)p\theta}{\alpha}$), in which the borrower's endowment is relatively abundant, the efficient level of insurance is provided, $c_1^i > 0$, and collateral level $\omega - c_1^i = \frac{(1-\lambda^*)p\theta}{\alpha} > 0$ is constant with respect to λ^i and ω . Because the commitment problem is not severe in both sub-cases, that is to say the limited commitment constraint is slack, then the threshold level of ω that separates the two is a function of λ^* rather than the actual temptation to default, λ^i .

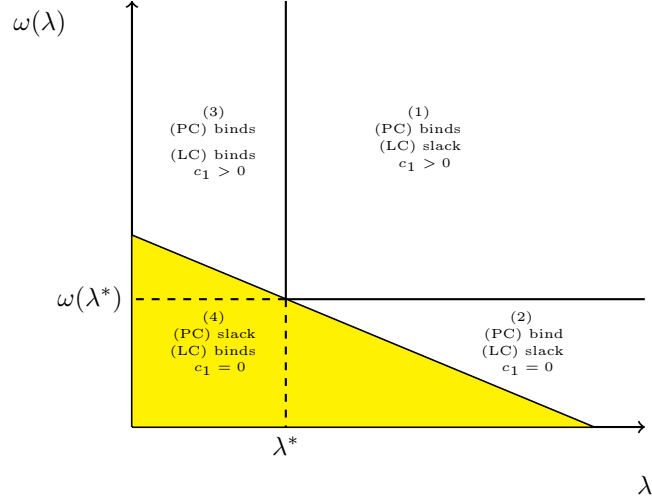


Figure 1: Solution to bilateral problem with info acquisition.

3.2 Bilateral clearing without monitoring

In Section 3 we defined a mechanism with bilateral clearing and no monitoring as a list of contracts $(\Sigma_i, x_{2,h}^i, x_{2,l}^i, c_{2,h}^{i,0}, c_{2,l}^i, c_1^i)_{i=L,H}$.

Conditional on no monitoring, the lender chooses a mechanism with bilateral clearing to

solve the following problem:

$$V^{bil,e=0} = \max \sum_{i=L,H} q_i \left[p \left\{ \Sigma^i u(x_{2h}^{i1}) + (1 - \Sigma^i) u(x_{2h}^{i0}) \right\} + (1 - p) u(x_{2l}^i) \right] \quad (12)$$

$$s.t. \quad \alpha c_1^i + p \left[\Sigma^i (1 - \lambda^i) \theta + (1 - \Sigma^i) c_{2h}^i \right] + (1 - p) c_{2l}^i \geq \alpha \omega \quad (13)$$

$$\omega \geq c_1^i \geq 0 \quad (14)$$

$$x_{2h}^{i0} + c_{2h}^i \leq \omega - c_1^i + \theta \quad (15)$$

$$x_{2h}^{i1} \leq \omega - c_1^i + \lambda^i \theta \quad (16)$$

$$x_{2l}^i + c_{2l}^i \leq \omega - c_1^i \quad (17)$$

$$(\lambda^i, \Sigma^i) \in \operatorname{argmax}_{(\hat{m}, \hat{\sigma})} \left\{ \alpha c_1^{\hat{m}} + p \left[\hat{\sigma} (1 - \lambda^i) \theta + (1 - \hat{\sigma}) c_{2h}^{\hat{m}} \right] + (1 - p) c_{2l}^{\hat{m}} \right\} \quad (18)$$

Constraint (13) is borrower i 's participation constraint, for $i \in \{L, H\}$. Constraint (14) is time $t = 1$ feasibility, (15) and (16) are time $t = 2$ feasibility in states $(s, \Delta) = (h, 0)$ and $(s, \Delta) = (h, 1)$ respectively; (17) is the time $t = 2$ feasibility condition in state l . Finally, constraint (18) is the incentive compatibility constraint for a borrower of type λ^i : the strategy pair (λ^i, Σ^i) is incentive compatible if there is no other strategy pair $(\hat{m}, \hat{\sigma})$ that yields a higher payoff. Notice that a borrower can deviate by reporting a different type $\hat{m} \neq \lambda^i$, by choosing a different default strategy $\hat{\sigma} \neq \Sigma^i$, or both.

The solution to this problem is analogous to that of the problem with central clearing and no monitoring, characterized in the next section. However, we show in Lemma 17 in Section 5 that any contract with bilateral clearing and no monitoring is dominated by a contract with central clearing. Therefore, because the goal of the paper is to compare bilateral versus central clearing, characterizing mechanisms with bilateral clearing and no monitoring is irrelevant to the question we want to address.

Finally, notice that the solution to the lender's decision problem with bilateral clearing is the same solution to the problem of a social planner subject to the frictions of 1) private information of the borrower's type; 2) limited commitment on the borrower's side at $t = 2$; and 3) bilateral matching. The last constraint implies that the social planner can allocate only

the resources which are available within the specific lender-borrower match, but not across different matches. These are the same constraints which a lender faces in choosing a menu of contracts to offer the borrower, implying that the solution to the lender's problem with bilateral clearing is constrained efficient.

4 Contracts with CCP clearing

With central clearing, borrowers and lenders submit the contract they agree upon to the CCP, which *novates* the contract. With novation, the original contract is suppressed and replaced by two contracts: one between the lender and the CCP, and one between the borrower and the CCP. The CCP takes the contract terms as given, but can require borrowers to post additional collateral, and lenders to contribute to a loss mutualization scheme.

We model novation by assuming that the CCP commits to a mechanism at the beginning of $t = 1$, and that lenders and borrowers negotiate over these contracts. A contract specifies transfers between borrowers and the CCP and transfers between lenders and the CCP as a function of public information. Because no transfer between the borrower and the lender takes place in the second period, a mechanism with central clearing consists of two contracts: a contract between the lender and the CCP, and a contract between the borrower and the CCP.

Contracts with central clearing may or may not prescribe monitoring by lenders. As in the environment with bilateral clearing, upon monitoring a lender learns the type λ^i of her counterparty. By assumption, this remains private information of the lender and the borrower. As a result, when designing a contract with monitoring, the CCP needs to take into account the incentives that lenders have to monitor their counterparty and report truthfully the information they learn.

A mechanism with central clearing and monitoring consists of contracts for lenders, $\{X_2^{i,\Delta}\}_{i=L,H}$ and contracts for borrowers, $\{C_1^i, C_{2,s}^i\}_{i=L,H}$. Contracts are executed after the lender reports to be matched with a borrower of type λ^i . The CCP promises to pay to the lender X_2^{i1} if the borrower defaults in equilibrium, and X_2^{i0} if the borrower does not default. At $t = 1$ the

borrower transfers $\omega - C_1^i$ units of the consumption good to the CCP. The CCP promises to pay the borrower $C_{2,l}^i$ in the low state ($s = l$) at $t = 2$, and $C_{2,h}^{i0}$ in the high state ($s = h$) at $t = 2$. We assume that repayments to the lender are independent of the idiosyncratic state s , because the initial link between the lender and the borrower is suppressed upon novation.

A strategy for a lender is a monitoring and reporting decision $(e, m_L) \in \{0, 1\} \times \{\lambda^H, \lambda^L\}$; a strategy for a borrower is a default decision function $\sigma^i \in \{0, 1\}$.

A mechanism with central clearing and no monitoring consists of contracts $\{X_2^{i,\Delta}\}_{i=L,H}$ and $\{\Sigma^i, C_1^i, C_{2s}^i\}_{i=L,H}$, which are executed if the borrower reports her type to be λ^i . Σ^i is the default decision that the CCP recommends to a borrower who reports her type to be λ^i ; Δ is the public history of the borrower's default/repayment decision. As with bilateral clearing, a strategy for a borrower is a pair $(m^i, \sigma^i) \in \{\lambda^L, \lambda^H\} \times \{0, 1\}$. A mechanism is incentive compatible if it is the borrower's best response to report truthfully her type, and then follow the recommendation Σ^i .

4.1 Central clearing with monitoring and borrowers' separation

Assuming that the monitoring decision as well as its outcome are not observable, contracts must induce lenders to monitor their counterparty and report truthfully the information they learn. With such contracts, the CCP acquires full information about borrowers' types, so it can design contracts that prevent borrowers' default in equilibrium. In order to induce monitoring and truth-telling, the CCP can punish a lender whose original counterparty defaults in equilibrium. The worst punishment is to choose $X_2^{i,1} = 0$. This is optimal, because it relaxes the incentive constraint for monitoring and truth-telling, without compromising the provision of insurance.

To simplify the notation, let $X_2^i = X_2^{i,0}$. Also, let V^{FI} denote the ex-ante value to the lender before the borrower's type is known. Then the CCP chooses contracts (X_2^H, X_2^L) and $\{C_1^i, C_{2,s}^i\}_{i=L,H}$ to solve the following maximization problem:

$$\begin{aligned}
 (P0^{FI}) \quad V^{FI} = \quad & \max \quad qu(X_2^H) + (1-q)u(X_2^L) - \gamma \\
 \text{s.t.} \quad & \alpha C_1^i + pC_{2h}^i + (1-p)C_{2l}^i \geq \alpha\omega, \quad \forall i
 \end{aligned} \tag{19}$$

$$C_{2h}^i \geq (1 - \lambda^i) \theta, \quad \forall i \quad (20)$$

$$0 \leq C_1^i \leq \omega, \quad \forall i \quad (21)$$

$$qX_2^H + (1 - q)X_2^L + qpC_{2h}^H + (1 - q)pC_{2h}^L + \\ + q(1 - p)C_{2l}^H + (1 - q)(1 - p)C_{2l}^L \leq \omega - qC_1^H - (1 - q)C_1^L + p\theta \quad (22)$$

$$-\gamma + qu(X_2^H) + (1 - q)u(X_2^L) \geq \max \left\{ u(X_2^L), \right. \quad (23)$$

$$\left. (q + (1 - q)(1 - p))u(X_2^H) + (1 - q)p[\sigma^{L'}u(0) + (1 - \sigma^{L'})u(X_2^H)] \right\} \\ \sigma^{L'} = \underset{\hat{\sigma} \in \{0,1\}}{\operatorname{argmax}} \left\{ (1 - \hat{\sigma})C_{2h}^H + \hat{\sigma}(1 - \lambda^L)\theta \right\} \quad (24)$$

Constraint (19) is the borrowers' participation constraint, (20) is the borrowers' limited commitment constraint, and (21) is $t = 1$ feasibility. Since the clearing process is channeled through the CCP, (22) defines $t = 2$ feasibility. Note that $t = 2$ feasibility is not defined for different realizations of borrowers' idiosyncratic state, as there is no aggregate uncertainty. Constraint (23) is the incentive compatibility condition for the lenders; we apply a max operator to the right-hand side of the constraint because lenders can deviate in two ways. First, they can choose not to monitor their counterparty and select the contract designed for λ^L types. In this case, (20) implies that all borrowers repay, so that lenders always consume X_2^L . Alternatively, lenders may choose not to monitor their counterparty and select the contract designed for λ^H types; such a deviation is detected by the CCP only if the borrower is a λ^L type who defaults in equilibrium. Constraint (24) defines the off-equilibrium optimal default strategy of a λ^L borrower who is entitled to consumption $C_{2,h}^H$.

In Appendix 7.4, we prove that we need to characterize only contracts that satisfy $C_{2,h}^H < (1 - \lambda^L)\theta$. Then, we replace $\sigma^{L'} = 1$ in constraints (23) and (24). Notice that the incentive compatibility constraint (23) generates a non-convex set of feasible allocations. To this end, define $w^H = u(X_2^H)$, $w^L = u(X_2^L)$, and rewrite $(P0^{FI})$ with the CCP choosing $\{w^i, C_1^i, C_{2s}^i\}_{i=H,L,s=h,l}$ to maximize lenders' ex-ante utility:

$$(\hat{P}^{FI}) \quad V^{FI} = \max \quad qw^H + (1 - q)w^L - \gamma \\ \text{s.t.} \quad \alpha C_1^i + pC_{2h}^i + (1 - p)C_{2l}^i \geq \alpha\omega, \quad \forall i \quad (25)$$

$$C_{2h}^i \geq (1 - \lambda^i) \theta, \quad \forall i \quad (26)$$

$$0 \leq C_1^i \leq \omega, \quad \forall i \quad (27)$$

$$\begin{aligned} & qu^{-1}(w^H) + (1 - q)u^{-1}(w^L) + qpC_{2h}^H + (1 - q)pC_{2h}^L + \\ & + q(1 - p)C_{2l}^H + (1 - q)(1 - p)C_{2l}^L \leq \omega - qC_1^H - (1 - q)C_1^L + p\theta \end{aligned} \quad (28)$$

$$\begin{aligned} & -\gamma + qw^H + (1 - q)w^L \geq \\ & \max \left\{ w^L, [q + (1 - q)(1 - p)]w^H + (1 - q)pu(0) \right\} \end{aligned} \quad (29)$$

One can solve problem (\hat{P}^{FI}) in two steps. In the first step, the CCP determines the contracts offered to borrowers, $\{C_1^i, C_{2s}^i\}_{i=H,L,s=h,l}$, to provide the maximal amount of resources in the second period. We denote such resources by Ω ; they consist of the amount of consumption good stored by the CCP from $t = 1$ to $t = 2$ and of all $t = 2$ borrowers' net payments. The contracts $\{C_1^i, C_{2s}^i\}_{i=H,L,s=h,l}$ must be feasible: they should satisfy the participation and the limited commitment constraints of the borrowers. Thus, contracts $\{C_1^i, C_{2s}^i\}_{i=H,L,s=h,l}$ solve the following problem:

$$\begin{aligned} (\hat{P}^{FI}) \quad \Omega = & \max_{\{C_1^i, C_{2h}^i, C_{2l}^i\}} \left[\omega - qC_1^H - (1 - q)C_1^L \right] + p\theta \\ & - q[pC_{2,h}^H + (1 - p)C_{2,l}^H] - (1 - q)[pC_{2,h}^L + (1 - p)C_{2,l}^L] \\ s.t. \quad & \alpha C_1^i + pC_{2h}^i + (1 - p)C_{2l}^i \geq \alpha\omega \\ & \omega \geq C_1^i \geq 0 \\ & C_{2,h}^i \geq (1 - \lambda^i)\theta \end{aligned}$$

In the second step, the CCP determines the contracts it offers to lenders, for a given amount of resources Ω . Such contracts should persuade lenders to monitor their counterparty and report truthfully the information that they learn; thus they solve

$$\begin{aligned} (\hat{P}^{FI}) \quad & \max_{\{w^H, w^L\} \in \mathbb{R}_+^2} \quad qw^H + (1 - q)w^L - \gamma \\ s.t. \quad & qu^{-1}(w^H) + (1 - q)u^{-1}(w^L) \leq \Omega \end{aligned}$$

$$\begin{aligned}
& -\gamma + qw^H + (1-q)w^L \geq \\
& \max \left\{ w^L, (q + (1-q)(1-p))w^H + (1-q)pu(0) \right\} \quad (30)
\end{aligned}$$

Assume without loss of generality that $u(0) = 0$. We can prove the following:

Lemma 4 $(C_1^i, C_{2h}^i, C_{2l}^i, w^i)_{i=L,H}$ solve the problem (\hat{P}^{FI}) if and only if $(C_1^i, C_{2h}^i, C_{2l}^i)_{i=L,H}$ solve $(\hat{P}b^{FI})$ and, letting Ω^* denote the value of the objective in $(\hat{P}b^{FI})$ at its solution, (w^H, w^L) solve $(\hat{P}a_{\Omega^*}^{FI})$.

The incentive compatibility (30) has a max operator on the right-hand side because lenders have two feasible deviations: they can i) not monitor and report a λ^L type or ii) not monitor and report a λ^H type. In the next lemma we show that in problem $(\hat{P}a_{\Omega^*}^{FI})$ we can restrict our attention to the space of utilities (w^H, w^L) where the best deviation for the lender is the first. This is the space of utilities (w^H, w^L) that satisfy $w^L \geq [q + (1-q)(1-p)]w^H$.

Lemma 5 Let $\Omega \in \mathfrak{R}_+$. For any $(w_H, w_L) \in \mathfrak{R}_+^2$ such that

$$qu^{-1}(w^H) + (1-q)u^{-1}(w^L) \leq \Omega \quad (31)$$

$$[q + (1-q)(1-p)]w^H = \max(w^L, (q + (1-q)(1-p))w^H) \quad (32)$$

$$-\gamma + qw^H + (1-q)w^L \geq (q + (1-q)(1-p))w^H \quad (33)$$

there exist $(w^{H'}, w^{L'}) \in \mathfrak{R}_+^2$ such that

$$qu^{-1}(w^{H'}) + (1-q)u^{-1}(w^{L'}) \leq \Omega \quad (34)$$

$$w^{L'} = \max(w^{L'}, (q + (1-q)(1-p))w^{H'}) \quad (35)$$

$$-\gamma + qw^{H'} + (1-q)w^{L'} \geq w^{L'} \quad (36)$$

and

$$qw^{H'} + (1-q)w^{L'} > qw^H + (1-q)w^L \quad (37)$$

Lemma 5 follows from convexity of the function $u^{-1}(\cdot)$ and the inefficiency that the incentive compatibility constraint (30) creates in different regions of the payoffs' space (w^H, w^L) . Technically, different payoffs (w^H, w^L) are induced by lotteries over different outcomes, $(u^{-1}(w^H), u^{-1}(w^L); q, 1 - q)$. If we hold constant the amount of resources, which is equal to $qu^{-1}(w^H) + (1 - q)u^{-1}(w^L)$, we keep constant the expected cost of these lotteries. Consider then any payoffs (w^H, w^L) such that the right-hand side of (30) equals to $[q + (1 - q)(1 - p)]w^H$. We can reduce w^H and increase w^L so that the lottery over outcomes that is induced by the new payoffs is a mean-preserving contraction of the lottery over outcomes that is induced by the original payoffs. Because of risk aversion, the new lottery must be strictly preferred to the original one. Since we can continue this process until the the right-hand side of (30) equals w^L , the result follows.

As a corollary of Lemma 5, we can rewrite problem $(\hat{P}a_{\Omega}^{FI})$ as follows:

$$(\hat{P}a_{\Omega}^{FI})' \quad \max_{\{w^H, w^L\} \in \mathfrak{R}_+^2} \quad qw^H + (1 - q)w^L - \gamma$$

$$s.t. \quad qu^{-1}(w^H) + (1 - q)u^{-1}(w^L) \leq \Omega \quad (38)$$

$$-\gamma + qw^H + (1 - q)w^L \geq w^L \quad (39)$$

$$w^L - [q + (1 - q)(1 - p)]w^H \geq 0 \quad (40)$$

Lemma 6 *A solution to problem $(\hat{P}a_{\Omega}^{FI})'$ exists (and is unique) if and only if $\Omega \geq \hat{\Omega}$, for $\hat{\Omega}$ which solves*

$$\hat{\Omega} = qu^{-1}\left(\frac{\gamma}{pq(1 - q)}\right) + (1 - q)u^{-1}\left(\frac{\gamma[q + (1 - q)(1 - p)]}{pq(1 - q)}\right) \quad (41)$$

Moreover, at the solution, equations (38) and (39) hold with equality.

Lemma 6 characterizes the optimal contract between lenders and the CCP, given available revenues Ω . Under the optimal contract, lenders matched with λ^H borrowers enjoy higher consumption than lenders matched with λ^L borrowers. Ex-ante, this contract induces lenders

to monitor their counterparty, anticipating that this might be a λ^H borrower. Ex-post this contract induces lenders matched with λ^L borrowers to truthfully reveal their counterparty's type. In fact the punishment that lenders would incur if caught lying, that is if their original counterparty defaults, is large enough to deter misreporting.

The remaining question concerns the consumption allocation implied by the optimal contract. The answer is provided in the following lemma.

Lemma 7 *A solution to problem $(\hat{P}b^{FI})$ is such that*

$$\begin{aligned} C_{2h}^i &= (1 - \lambda^i)\theta, & C_{2l}^i &= 0, \\ C_1^i &= \max \left\{ 0, \omega - \frac{p(1 - \lambda^i)\theta}{\alpha} \right\}. \end{aligned}$$

And

$$\Omega = p\theta + \omega - \begin{cases} q(p(1 - \lambda^H)\theta) + (1 - q)(p(1 - \lambda^L)\theta) & \text{if } \omega \leq \frac{p(1 - \lambda^H)\theta}{\alpha} \\ q\left(\omega + (\alpha - 1)\frac{p(1 - \lambda^H)\theta}{\alpha}\right) + (1 - q)(p(1 - \lambda^L)\theta) & \text{if } \frac{p(1 - \lambda^H)\theta}{\alpha} < \omega \leq \frac{p(1 - \lambda^L)\theta}{\alpha} \\ q\left(\omega + (\alpha - 1)\frac{p(1 - \lambda^H)\theta}{\alpha}\right) + (1 - q)\left(\omega + (\alpha - 1)\frac{p(1 - \lambda^L)\theta}{\alpha}\right) & \text{if } \omega > \frac{p(1 - \lambda^L)\theta}{\alpha} \end{cases} \quad (42)$$

To gain intuition for Lemma 7, note that, when contracts are cleared centrally, there is no need of collateral for insurance purposes, because the CCP can fully insure lenders by pooling risk. Hence, the objective in problem $(\hat{P}b^{FI})$ is to minimize collateral requirements. The limited commitment constraint always binds, and consumption is determined residually from the borrowers' participation constraint in the first period. When collateral is abundant, borrowers' $t = 1$ consumption is pinned down by the binding participation constraint, whereas when collateral is scarce borrowers' $t = 1$ consumption equals zero.

We can combine Lemma 6 and Lemma 7 to characterize the solution to the problem $(\hat{P}b^{FI})$. First, define the function

$$\phi(\gamma) = qu^{-1} \left(\frac{\gamma}{pq(1 - q)} \right) + (1 - q)u^{-1} \left(\gamma \left[\frac{1 - p(1 - q)}{pq(1 - q)} \right] \right)$$

which maps any value of $\gamma \geq 0$ to the minimum aggregate resources (i.e. $t = 2$ consumption goods) consistent with the existence of a solution to the CCP full information problem ($P0^{FI}$).

Further, define the threshold $\hat{\gamma}^{(\omega)}$ as the unique solution to

$$\begin{aligned} \phi(\hat{\gamma}^{(\omega)}) = & q \left[\min \left\{ \omega, \frac{(1 - \lambda^H)p\theta}{\alpha} \right\} + \lambda^H p\theta \right] \\ & + (1 - q) \left[\min \left\{ \omega, \frac{(1 - \lambda^L)p\theta}{\alpha} \right\} + \lambda^L p\theta \right] \end{aligned} \quad (43)$$

Thus, $\hat{\gamma}^{(\omega)}$ denotes the largest value of γ which, for a given value of ω , is such that a solution to the CCP full information problem ($P0^{FI}$) exists.

Proposition 8 *A solution to problem ($P0^{FI}$) exists and is unique if and only if $\gamma \leq \hat{\gamma}^{(\omega)}$. Then Ω is given by equation (42) and*

$$V^{FI} = w^L,$$

for w^L solving

$$qu^{-1} \left(w^L + \frac{\gamma}{q} \right) + (1 - q)u^{-1}(w^L) = \Omega.$$

Proof. The conclusion follows combining Lemma 4, Lemma 5, Lemma 6, and Lemma 7. ■

Intuitively, when the CCP wants to implement contracts with monitoring, it needs to take into account that a lender may deviate by choosing not to monitor her counterparty, while announcing that monitoring occurred and that the counterparty's pledgeability type is either *i*) low, or *ii*) high. Constraint (39) guarantees that lenders will not undertake deviation *i*), requiring the CCP to reward members facing a high-quality counterparty relative to those facing a low-quality counterparty. Constraint (40) guarantees that lenders will not take deviation *ii*), requiring the CCP to ensure that the members who face a low-quality counterparty do not get penalized excessively relative to those facing a high-quality counterparty. In other words, the CCP needs to make payments that are *far enough* between lenders matched with different borrower types, but also *large enough* to sustain the cost of monitoring. Importantly,

these two conditions can be jointly satisfied only if the cost of monitoring is low relative to the resources available to the CCP, namely if $\gamma \leq \hat{\gamma}(\omega)$, for $\hat{\gamma}(\omega)$ defined in (43).

4.2 Central clearing without monitoring

The CCP may prefer to offer contracts that do not require to monitor borrowers. Such contracts are chosen to solve:

$$V^{CCP, e=0} = \max \sum_i q_i [\Sigma^i u(X_2^{i,1}) + (1 - \Sigma^i) u(X_2^{i,0})] \quad (44)$$

$$s.t. \quad \alpha C_1^i + p[\Sigma^i(1 - \lambda^i)\theta + (1 - \Sigma^i)C_{2h}^i] + (1 - p)C_{2l}^i \geq \alpha\omega \quad (45)$$

$$0 \leq C_1^i \leq \omega \quad (46)$$

$$\begin{aligned} \sum_i q_i \left[\Sigma^i \left\{ X_2^{i,1} + p(1 - \lambda^i)\theta \right\} + (1 - \Sigma^i) \left\{ X_2^{i,0} + pC_{2h}^i \right\} \right. \\ \left. + (1 - p)C_{2l}^i \right] \leq p\theta + \sum_i q_i \{\omega - C_1^i\} \end{aligned} \quad (47)$$

$$(\lambda^i, \Sigma^i) \in \operatorname{argmax}_{(\hat{m}, \hat{\sigma})} \left\{ \alpha \hat{c}_1^{\hat{m}} + p \left[\hat{\sigma}(1 - \lambda^i)\theta + (1 - \hat{\sigma})C_{2h}^{\hat{m}} \right] + (1 - p)C_{2l}^{\hat{m}} \right\} \quad (48)$$

Concavity of the utility function $u(\cdot)$ implies that it is optimal to choose $X_2^{H,1} = X_2^{H,0} = X_2^{L,1} = X_2^{L,0}$. Therefore we simplify the notation and write $X_2^{i,\Delta} = X_2$ in (44) and in (47). In addition, we ignore contracts such that good type borrowers default in equilibrium, as the next lemma shows that they are not optimal.

Lemma 9 *Without loss of generality, we can ignore all contracts that recommend the strategy $\Sigma^H = 1$. Therefore, λ^H borrowers never default in equilibrium.*

According to Lemma 9, we have to consider only two classes of contracts: contracts in which no borrower defaults in $t = 2$, that is $\Sigma^H = \Sigma^L = 0$, and contract in which only λ^H borrowers repay in $t = 2$, whereas λ^L borrowers default in equilibrium, that is $\Sigma^H = 0$ and $\Sigma^L = 1$.

4.2.1 The optimal contract without default: pooling over λ^L

Without monitoring, the optimal contract that guarantees no defaults in equilibrium is a pooling contract that ignores borrowers' heterogeneity and treats them all as if they were the worst borrower type. More specifically, consider the following modified problem:

$$(P^L) \quad V^{CCP, \lambda^L} = \max u(X_2) \quad (49)$$

$$s.t. \quad \alpha C_1 + pC_{2h} + (1-p)C_{2l} \geq \alpha\omega \quad (50)$$

$$C_{2h} \geq (1 - \lambda^L)\theta \quad (51)$$

$$0 \leq C_1 \leq \omega \quad (52)$$

$$X_2 + pC_{2h} + (1-p)C_{2l} \leq \omega - C_1 + p\theta \quad (53)$$

Constraint (50) is the participation constraint, and (51) is the limited commitment constraint of λ^L borrowers. Equations (52) and (53) are $t = 1$ and $t = 2$ resource constraints, where in (53) no borrower defaults in equilibrium.

Lemma 10 *A solution to (P^L) is such that: i) $C_1 < \omega$; ii) (53) always binds; iii) $C_{2,l} = 0$.*

Lemma 11 *Let $(X_2, C_1^i, C_{2h}^i, C_{2l}^i)$ be the solution to $(P0)$, with $\Sigma^H = 0$ and $\Sigma^L = 0$. Then, $C_1^H = C_1^L$, $C_{2,l}^H = C_{2,l}^L$, and $(X_2, C_1^L, C_{2,h}^L, C_{2,l}^L)$ solve problem (P^L) .*

According to Lemma 11, problem (P^L) characterizes the optimal contract where no borrower defaults in equilibrium. This contract resembles the one with monitoring and bilateral clearing when the borrower type is λ^L . The only difference between the two contracts is the resource constraint, which, with central clearing, permits risk pooling over investment returns, $\tilde{\theta}$. As in the previous analysis, $\alpha > 1$ implies $C_{2,l} = 0$.

It is easy to see that (51) binds. Then C_1 is determined residually from the participation constraint (50). The next lemma summarizes these results.

Lemma 12 *The solution to problem (P^L) is such that the limited commitment constraint always binds, $C_{2,h} = (1 - \lambda^L)\theta$, and $C_1 = \max \left\{ 0, \omega - \frac{(1 - \lambda^L)p\theta}{\alpha} \right\}$.*

Therefore we can rewrite V^{CCP,λ^L} as

$$V^{CCP,\lambda^L} = \begin{cases} u\left(\frac{(1-\lambda^L)p\theta}{\alpha} + p\theta\lambda^L\right) & \text{if } \omega \geq \frac{(1-\lambda^L)p\theta}{\alpha} \\ u(\omega + p\theta\lambda^L) & \text{if } \omega < \frac{(1-\lambda^L)p\theta}{\alpha} \end{cases}$$

4.2.2 The Contract in which λ^L borrowers default: pooling over λ^H

The optimal contract that induces λ^L borrowers to default in equilibrium has an intuitive interpretation: its outcome is equivalent to the CCP ignoring the heterogeneity across borrowers and treat them all as if they were λ^H type borrowers.

More specifically, consider the following modified problem:

$$(P^H) \quad V^{CCP,\lambda^H} = \max_{(X_2, C_1, C_{2h}, C_{2l})} u(X_2) \quad (54)$$

$$s.t. \quad \alpha C_1 + pC_{2h} + (1-p)C_{2l} \geq \alpha\omega \quad (55)$$

$$(1-\lambda^L)\theta \geq C_{2h} \geq (1-\lambda^H)\theta \quad (56)$$

$$0 \leq C_1 \leq \omega \quad (57)$$

$$\begin{aligned} X_2 + qpC_{2h} + (1-q)p(1-\lambda^L)\theta + q(1-p)C_{2l} + \\ + (1-q)pC_{2l} \leq \omega - C_1 + p\theta \end{aligned} \quad (58)$$

Constraint (55) is the participation constraint and (56) is the limited commitment constraint of λ^H borrowers. Equations (57) and (58) are $t = 1$ and $t = 2$ resource constraints. Note that constraint (58) assumes that λ^L borrowers always default in equilibrium.

Lemma 13 *A solution to (P^H) is such that: i) (57), is always slack and $C_1 < \omega$; ii) (58), always binds; iii) $C_{2,l} = 0$.*

Lemma 14 *Let $(X_2, C_1^i, C_{2h}^i, C_{2l}^i)$ denote the solution to problem $(P0)$, with $\Sigma^H = 0$ and $\Sigma^L = 1$. Then $C_1^H = C_1^L$, $C_{2,h}^H = C_{2,l}^L$, and $(X_2, C_1^H, C_{2,h}^H, C_{2,l}^H)$ solve problem (P^H) .*

According to Lemma 14 problem (P^H) characterizes optimal contracts that induce λ^L borrowers to default in equilibrium. We characterize such optimal contracts in the next lemma.

Lemma 15 *The solution to problem (P^H) is such that*

1. If $\omega \geq \frac{(1-\lambda^L)p\theta}{\alpha}$
 - (a) If $q \geq \frac{1}{\alpha}$, then $C_{2h} = (1 - \lambda^H)\theta$, $C_1 = \omega - \frac{(1-\lambda^H)p\theta}{\alpha}$.
 - (b) If $q < \frac{1}{\alpha}$, then $C_1 = \omega - \frac{(1-\lambda^L)p\theta}{\alpha}$, $C_{2h} = (1 - \lambda^L)\theta$
2. $\frac{(1-\lambda^L)p\theta}{\alpha} > \omega \geq \frac{(1-\lambda^H)p\theta}{\alpha}$
 - (a) If $q \geq \frac{1}{\alpha}$, then $C_{2h} = (1 - \lambda^H)\theta$, $C_1 = \omega - \frac{(1-\lambda^H)p\theta}{\alpha}$.
 - (b) If $q < \frac{1}{\alpha}$, then $C_1 = 0$, $C_{2h} = \frac{\alpha\omega}{p}$
3. If $\omega < \frac{(1-\lambda^H)p\theta}{\alpha}$, then $C_1 = 0$, $C_{2h} = (1 - \lambda^H)\theta$

Therefore we can rewrite V^{CCP, λ^H} as

$$V^{CCP, \lambda^H} = \begin{cases} u(\omega + p\theta[q\lambda^H + (1-q)\lambda^L]) & \text{if } \omega < \frac{(1-\lambda^H)p\theta}{\alpha} \\ u\left(\frac{(1-\lambda^H)p\theta}{\alpha} + p\theta[q\lambda^H + (1-q)\lambda^L]\right) & \text{if } q \geq \frac{1}{\alpha} \text{ and } \omega \geq \frac{(1-\lambda^H)p\theta}{\alpha} \\ u\left(\frac{(1-\lambda^H)p\theta}{\alpha} + p\theta[q\lambda^H + (1-q)\lambda^L] + (1-q\alpha)\left[\omega - \frac{(1-\lambda^H)p\theta}{\alpha}\right]\right) & \text{if } q < \frac{1}{\alpha} \text{ and } \frac{(1-\lambda^H)p\theta}{\alpha} \leq \omega < \frac{(1-\lambda^L)p\theta}{\alpha} \\ u\left(\frac{(1-\lambda^L)p\theta}{\alpha} + p\theta\lambda^L\right) & \text{if } q < \frac{1}{\alpha} \text{ and } \omega \geq \frac{(1-\lambda^L)p\theta}{\alpha} \end{cases}$$

Lemma 15 shows that the properties of the pooling contract over λ^H hinge on two key parameters: the fraction q of high-pledgeability borrowers and the cost of collateral $\frac{1}{\alpha}$. The relative size of these parameters governs the effect that collateral has on the total amount of resources available to the CCP at $t = 2$. The reason is that reducing the homogeneous collateral requirement across borrowers at $t = 1$ has two opposing effects when the CCP (optimally) accepts that λ^L borrowers default in equilibrium. First, because borrowers' preferences are biased toward $t = 1$ consumption, reducing collateral requirements has the potential of increasing the amount of resources available to the CCP at $t = 2$. This increase could occur because the reduction in collateral and corresponding increase in consumption at $t = 1$ leads to a more than proportional reduction in consumption at $t = 2$ for a constant level of expected utility, as $\alpha > 1$. However, a second indirect effect of reducing collateral requirements for all borrowers by offering a pooling contract over λ^H is the reduction in the aggregate resources available to the CCP at $t = 2$, because λ^L borrowers default in equilibrium. Intuitively, the

first effect is stronger than the second effect if and only if the fraction of λ^H borrowers is large enough, i.e. $q > \frac{1}{\alpha}$. This last condition can also be rewritten as $q(\alpha - 1) > 1 - q$, where the left-hand-side is the benefit of lower collateral requirements, weighted by the fraction of λ^H borrowers, and the right-hand-side is the cost of lower collateral requirements, weighted by the fraction of λ^L borrowers.

When $q \geq \frac{1}{\alpha}$, maximizing the amount of resources available at $t = 2$ is equivalent to minimizing the collateral requirement in $t = 1$. Then, the limited commitment constraint of a λ^H borrower binds, $C_{2,h} = (1 - \lambda^H)\theta$, and consumption in the first period is determined residually from the participation constraint (55) and the feasibility condition $C_1 \geq 0$.

When $q < \frac{1}{\alpha}$, maximizing the amount of resources available at $t = 2$ is equivalent to minimizing the resources consumed by λ^L borrowers due to their defaults. This is accomplished by choosing the largest feasible collateral requirement, up to the point where the effect of λ^L borrowers' default on $t = 2$ resources is minimized. When $\omega < \frac{(1-\lambda^L)p\theta}{\alpha}$, collateral is scarce and borrowers are asked to post their entire endowment as collateral, which results in $C_1 = 0$. When $\omega \geq \frac{(1-\lambda^L)p\theta}{\alpha}$, the contract chosen by the CCP effectively replicates the allocation of a pooling contract over λ^L borrowers. As a result, the consumption allocation of λ^L borrowers is such that their limited commitment and participation constraints hold at equality. In this case λ^L borrowers are treated exactly as they would be in a full information contract, therefore they do not earn any information rents.

4.2.3 Equilibrium contracts with central clearing and no information acquisition

The results discussed throughout Section 4.2 show that contracts without monitoring can impose costs to lenders in terms of inefficient collateral requirements. The following lemma characterizes the optimal contract with central clearing when there is no monitoring activity.

Lemma 16 *The optimal contract with central clearing and no information acquisition is*

- (i) *Pooling over λ^H if $q \geq \frac{1}{\alpha}$, or if $q < \frac{1}{\alpha}$ and $\omega < \frac{(1-\lambda^L)p\theta}{\alpha}$;*
- (ii) *Pooling over λ^L if $q < \frac{1}{\alpha}$ and $\omega \geq \frac{(1-\lambda^L)p\theta}{\alpha}$.*

When lenders acquire no information about borrowers' types, optimal contracts ignore heterogeneity in borrowers' default risk. More precisely, if all borrowers are treated as if they were λ^L types, λ^H borrowers end up posting an excessive amount of collateral. This policy is costly for lenders because it requires them to forgo a larger amount of consumption good in $t = 2$ to satisfy borrowers' participation constraint. When the population of λ^H borrowers is relatively large, i.e. $q \geq \frac{1}{\alpha}$, the policy of treating all borrowers as λ^L types is not efficient for the CCP, which thus chooses to let λ^L borrowers default in equilibrium.

If instead all borrowers are treated as if they were λ^H types, λ^L borrowers post too little collateral and default in equilibrium at $t = 2$. This policy also imposes costs on lenders, because the defaults of λ^L borrowers reduce the amount of consumption good available to the CCP at $t = 2$. When the population of λ^L types is relatively large, and collateral is abundant relative to the commitment problem of λ^L borrowers, i.e. $q < \frac{1}{\alpha}$ and $\omega \geq \frac{(1-\lambda^L)p\theta}{\alpha}$, it is inefficient for the CCP to let λ^L borrowers default in equilibrium.

Lemma 16 then implies that:

$$V^{CCP,e=0} = \begin{cases} V^{CCP,\lambda^L} & \text{if } \omega \geq \frac{(1-\lambda^L)p\theta}{\alpha} \text{ and } q < \frac{1}{\alpha} \\ V^{CCP,\lambda^H} & \text{otherwise.} \end{cases} \quad (59)$$

where V^{CCP,λ^H} is defined in Section 4.2.2, and V^{CCP,λ^L} is defined in Section 4.2.1. Finally, as with bilateral clearing, notice that the solution to the decision problem with central clearing is the same solution to the problem of a social planner subject to the frictions of 1) private information of the borrower's type; 2) limited commitment on the borrower's side at $t = 2$; 3) lenders' private information on their use of the information acquisition technology. As a consequence, the optimal contract with central clearing is constrained efficient. The decision problem with central clearing is not constrained by the resources available within the specific lender-borrower match, as it is with bilateral clearing, and the CCP can reallocate resources across different matches. However, the decision problem with central clearing is subject to the additional constraint arising from the lenders' information acquisition decision.

5 Optimal Clearing

In the previous sections, we characterized feasible contracts under different clearing arrangements. In this section, we determine lenders' choice of clearing arrangement, and refer to it as the optimal clearing arrangement.

First, we prove that bilateral clearing is optimal only if lenders monitor their counterparty. More precisely, we prove that contracts with bilateral clearing and no information acquisition are not optimal. The reason is that a CCP can always replicate such contracts, and in addition it can provide insurance against idiosyncratic risks. Lemma 17 formalizes this result.

Lemma 17 *The optimal contract with CCP clearing and no monitoring, i.e. the solution to (44), dominates the optimal contract with bilateral clearing and no monitoring, i.e. the solution to (12).*

Second, in Lemma 18 we prove that for $\hat{\gamma}^{(w)}$ defined in (43), if $\gamma \leq \hat{\gamma}^{(w)}$ central clearing is the optimal arrangement.

Lemma 18 *If $\gamma \leq \hat{\gamma}^{(w)}$ defined in (43), then the contract with bilateral clearing and monitoring is dominated either by the contract with CCP clearing and pooling over λ^L or by the contract with CCP clearing and monitoring.*

In the proof of Lemma 18, we show that lenders would prefer the contract with bilateral clearing and monitoring over the contract with central clearing and pooling over λ^L only if, given the monitoring cost γ , the value of facing a λ^H counterparty is significantly higher than the value of facing a λ^L counterparty. However, if this is the case and $\gamma \leq \hat{\gamma}^{(w)}$, a CCP can replicate such bilateral contracts and obtain enough resources at $t = 2$ to induce lenders to monitor their counterparties and report truthfully their type. Further, the CCP can transfer some resources from lenders facing a λ^H counterparty to lenders facing a λ^L counterparty, without violating lenders' incentive compatibility constraints. As a result, central clearing improves on bilateral clearing by providing insurance against the risk of facing a counterparty type λ^L .

Third, in Lemma 19 we prove that bilateral clearing is optimal only if λ^H is sufficiently large and λ^L is sufficiently small.

Lemma 19 *If $\lambda^L \geq \bar{\lambda}^L \equiv \max\left\{\lambda^*, 1 - \frac{\alpha\omega}{p\theta}\right\}$, the contract with central clearing and pooling over λ^L dominates the contract with information acquisition and bilateral clearing. If $\lambda^H < \underline{\lambda}^H = 1 - \frac{\alpha\omega}{p\theta}$ or $\lambda^H > \underline{\lambda}^H > \lambda^*$, the contract with central clearing and pooling over λ^H dominates the contract with information acquisition and bilateral clearing.*

Corollary 20 *Bilateral clearing is never optimal if either of these conditions hold:*

- i) $\lambda^L \geq \bar{\lambda}^L \equiv \max\left\{\lambda^*, 1 - \frac{\alpha\omega}{p\theta}\right\}$, or*
- ii) $\lambda^H < \underline{\lambda}^H = 1 - \frac{\alpha\omega}{p\theta}$, or*
- iii) $\lambda^H > \underline{\lambda}^H > \lambda^*$, or*
- iv) $\gamma \leq \hat{\gamma}^{(w)}$.*

Corollary 20 provides sufficient conditions for central clearing to be optimal. These sufficient conditions can be understood in terms of the value of information under different clearing arrangements. Specifically, Corollary 20 states that central clearing is optimal if either information about the counterparty type has no value with bilateral clearing, cases *i)-iii)*, or if the value of information about counterparty type is larger with central clearing than with bilateral clearing (case *iv)*). In case *i)*, with bilateral clearing, the limited commitment constraint is slack for both borrowers' types. Thus lenders do not need any information about their counterparty and prefer central clearing, which provides insurance against uncertain investment risk. Similarly, in the economies described by cases *ii)* and *iii)* information about the counterparty type has no value, although for different reasons. These are economies where, with bilateral clearing, optimal contracts require borrowers to post the maximum feasible amount of collateral (i.e. $c_1 = 0$) regardless of their type. Thus, even if a lender knew the type of her counterparty, she could not require λ^L -borrowers to post more collateral than

she already posted.¹⁴ As a consequence, lenders prefer central clearing because it provides insurance against uncertain investment risk. Finally, in economies where the monitoring cost is relatively small (case *iw*), the CCP can induce monitoring by lenders, and information is more valuable with central clearing because the CCP can provide full insurance against the idiosyncratic return risk, and partial insurance against the counterparty-type risk.

5.1 Optimal bilateral clearing: the CCP contract where full information is not implementable ($\gamma > \hat{\gamma}^{(w)}$).

In the rest of the analysis, we consider parameter configurations that do not satisfy any of the conditions of Corollary 20. Then, a trade-off between bilateral and central clearing arises.

Central clearing has the advantage of providing insurance by pooling risk over idiosyncratic uncertainty and, as a result, the potential to economize on the use of collateral necessary to insure against idiosyncratic risk. However, since $\gamma > \hat{\gamma}^{(w)}$, monitoring is not incentive feasible for the CCP. Without the information generated by monitoring, the CCP must offer contracts that require all traders to post the same amount of collateral, which is associated either to a low-pledgeability or a high-pledgeability counterparty. Thus, central clearing has the limitation of requiring a fraction of the borrowers' population to post either excessive or insufficient collateral levels necessary to provide incentives to repay. On the other hand, bilateral clearing has the disadvantage of calling for larger collateral requirements to insure against idiosyncratic risk, but the benefit of preserving the incentives to monitor a counterparty, as long as the monitoring cost γ is not too large, and allow collateral requirements to be tailored to the type of counterparty. These insights are formalized in the following proposition.

Proposition 21 *Let $Y \subseteq \mathbb{R}_+^3 \times (0, 1)^4$ and $y = (\omega, \alpha, \theta, p, q, \lambda^H, \lambda^L)$ denote an element of Y . Suppose that $\lambda^L < \bar{\lambda}^L \equiv \max\left\{\lambda^*, 1 - \frac{\alpha\omega}{p\theta}\right\}$, $\lambda^H \geq \underline{\lambda}^H \equiv 1 - \frac{\alpha\omega}{p\theta}$, and $\underline{\lambda}^H \leq \lambda^*$. Let $\hat{\gamma}^{(w)} : Y \rightarrow \mathbb{R}_+$ be the map defined for any vector y in (43), and $\bar{\gamma} : Y \rightarrow \mathbb{R}_+$ map any vector*

¹⁴Economies described by case *ii*) correspond to area 4 in figure 1, where ω is so small that both types of borrowers are required to post their entire endowment as collateral. Economies described by case *iv*) correspond to area 2 in figure 1 for a λ^H borrower, and either area 2 or the part of area 4 such that $\omega < \omega(\lambda^*)$ for a λ^L borrower. The collateral good is not very abundant and, even if the limited commitment constraint is slack for a λ^H borrower, collateral requirement is at its maximum even for such borrower.

y to a value of monitoring cost:

$$\phi(\hat{\gamma}^{(\omega)}) = q \left[\frac{p\theta}{\alpha}(1 - \lambda^H) + p\theta\lambda^H \right] + (1 - q)[Q_2 + p\theta\lambda^L] \quad (60)$$

$$\bar{\gamma} = qA + (1 - q)B - C \quad (61)$$

where

$$Q_2 = \begin{cases} \omega & \text{if } \omega < \frac{p\theta}{\alpha}(1 - \lambda^L) \\ \frac{p\theta}{\alpha}(1 - \lambda^L) & \text{otherwise} \end{cases} \quad (62)$$

and

$$A = \begin{cases} pu \left(\frac{p\theta}{\alpha}(1 - \lambda^*) + \lambda^*\theta \right) + (1 - p)u \left(\frac{p\theta}{\alpha}(1 - \lambda^*) \right) & \text{if } \lambda^H \geq \lambda^* \\ pu \left(\frac{p\theta}{\alpha}(1 - \lambda^H) + \lambda^H\theta \right) + (1 - p)u \left(\frac{p\theta}{\alpha}(1 - \lambda^H) \right) & \text{otherwise} \end{cases} \quad (63)$$

$$B = \begin{cases} pu \left(\frac{p\theta}{\alpha}(1 - \lambda^L) + \theta\lambda^L \right) + (1 - p)u \left(\frac{p\theta}{\alpha}(1 - \lambda^L) \right) & \text{if } \omega > \frac{p\theta}{\alpha}(1 - \lambda^L) \\ pu(\omega + \theta\lambda^L) + (1 - p)u(\omega) & \text{if } \frac{p\theta}{\alpha}(1 - \lambda^H) < \omega < \frac{p\theta}{\alpha}(1 - \lambda^L) \end{cases} \quad (64)$$

$$C = \begin{cases} u \left(\frac{p\theta}{\alpha}(1 - \lambda^L) + p\theta\lambda^L \right) & \text{if } \omega > \frac{p\theta}{\alpha}(1 - \lambda^L) \text{ and } q < \frac{1}{\alpha} \\ u \left(\frac{p\theta}{\alpha}(1 - \lambda^H) + p\theta(q\lambda^H + (1 - q)\lambda^L) \right) & \text{if } q > \frac{1}{\alpha} \\ u(\omega(1 - \alpha q) + p\theta[1 - (1 - q)(1 - \lambda^L)]) & \text{if } \frac{p\theta}{\alpha}(1 - \lambda^H) < \omega < \frac{p\theta}{\alpha}(1 - \lambda^L) \text{ and } q \leq \frac{1}{\alpha}. \end{cases} \quad (65)$$

Then bilateral clearing with information acquisition is the optimal clearing arrangement if and only if $\gamma \in (\hat{\gamma}^{(\omega)}, \bar{\gamma})$.

Proposition 21 proves that lenders prefer bilateral clearing for intermediate values of the monitoring cost γ . The reason is that $\hat{\gamma}^{(\omega)}$ is the lower bound on the cost of monitoring, γ , such that the CCP can only offer pooling contracts. Since these are the only contracts that entail a trade-off with bilateral clearing, then $\gamma > \hat{\gamma}^{(\omega)}$ is necessary for the optimality of bilateral clearing. Similarly, $\bar{\gamma}$ is the largest value of γ such that the value of tailoring collateral requirements to the severity of the limited commitment friction, net of the cost of

monitoring, exceeds the value of insurance against uncertain returns. When $\gamma \in (\hat{\gamma}^{(\omega)}, \bar{\gamma})$, the insurance over uncertain returns provided by the CCP does not compensate lenders for the inefficient use of collateral due to the lack of information over the counterparty quality. Thus lenders choose to clear contracts bilaterally and acquire information about their borrowers.

Naturally, the bounds on γ depend on the parameters of the model; among them, the degree of risk-aversion, the opportunity cost of collateral, and the degree of heterogeneity of the population of borrowers play an important role. Proposition 21 also implies that for any value of λ^H and ω , $\bar{\gamma} < 0$ either when q is arbitrarily close to unity (a large presence of λ^H -type borrowers) or when q is arbitrarily close to 0 (a large presence of λ^L -type borrowers). When q is close to unity, it is very likely for a borrower to be a λ^H type. In these cases, it is optimal to save on the monitoring cost and clear the contract centrally. On the other hand, when q is close to 0, it is very likely for a lender to face a λ^L -type borrower, so it does not pay off to monitor a borrower and clear the contract bilaterally. In these cases, learning the counterparty type is not valuable, and central clearing still allows to pool investment risk. Thus, we expect bilateral clearing to emerge only if there is sufficient uncertainty over counterparty types. On the other hand, bilateral clearing is preferred for a larger set of parameters when α , the opportunity cost of collateral, increases. This increase causes the threshold $\hat{\gamma}^{(\omega)}$ to (weakly) decrease, implying that monitoring and borrowers' separation under central clearing is not implementable for a larger set of parameters.¹⁵ Moreover, for sufficiently large values of p and q , the threshold $\bar{\gamma}$ is also weakly increasing in α : as a result, the set of monitoring costs satisfying the assumptions of Proposition 21 is larger.¹⁶ Similarly, the degree of risk-aversion plays an important role: in general, the threshold $\bar{\gamma}$ is smaller the higher is the degree of risk aversion. Intuitively, the advantage of the CCP in pooling risk over uncertain returns is larger

¹⁵The threshold $\hat{\gamma}^{(\omega)}$ is defined by equation (43): an increase in α causes the right hand side of (43) to weakly decrease, and, since the function $\phi(\gamma)$ is increasing in γ , then $\hat{\gamma}^{(\omega)}$ must (weakly) decrease as a consequence. As a consequence the set of γ values for which $\gamma \leq \hat{\gamma}^{(\omega)}$ becomes smaller. As shown in the proof of Lemma 18, this implies that monitoring and borrowers' separation are no longer feasible under central clearing.

¹⁶That $\bar{\gamma}$ increases in α can be seen from equations (63)-(65). Consider for simplicity an increase in α sufficiently large to satisfy $q > \frac{1}{\alpha}$. Then C decreases and, as long as p is sufficiently large then A increases, as λ^* (weakly) increases. With q sufficiently large the change in A dominates the change in B , resulting in an overall increase in $\bar{\gamma}$. If the increase in λ^* , however, is large enough that $\lambda^H < \lambda^*$, then A decreases, but due to strict concavity of u , any change in A is dominated by a change in C for p and q sufficiently large.

the more risk-averse the lenders are.

Intuitively, large values of α can be associated with financial institutions such as hedge funds or broker-dealers, whose opportunity cost of collateral is higher than, say, that of money market funds.¹⁷ In this respect, our results are broadly consistent with evidence of dealers and hedge funds clearing a substantial share of their trades bilaterally, whereas money market funds are more likely to rely on financial market infrastructure (e.g. General Collateral Finance Repo Service (GCF Repo) and triparty settlement).¹⁸ Analogously, our results are consistent with central clearing arising endogenously in markets where participants are homogenous in terms of their business type (in the model, q close to 1 or 0), when we interpret the pledgeability parameter λ as the riskiness in a counterparty's set of activities.¹⁹

6 Conclusions

This paper characterizes optimal clearing arrangements for financial transactions in a model where insurance is valuable because of uncertain returns to investment and heterogenous quality of trading counterparties. The contribution of the analysis is the identification of a trade-off between clearing bilaterally and channeling clearing services through a CCP. This trade-off arises when incentives to monitor bilateral trades are incompatible with the risk pooling activity of the CCP. Thus, even though the motivation for central clearing might arise from reasons outside the model, such as systemic risk consequences of opaque bilateral positions, the consequence of mandatory CCP clearing is a loss of information across markets due to decreased incentives to monitor trading partners. This result should not of course lead to the conclusion that CCP's are not useful in sharing risk in markets. It rather highlights the importance of the risk of the underlying assets and the degree of heterogeneity of market participants in determining whether CCP's can perform their risk sharing function effectively.

¹⁷At least under normal circumstances, disregarding events as money market funds *breaking the buck*.

¹⁸As an example, for evidence related to the US repo market see the Office of Financial Research Brief Paper no. 17-04, *Benefits and Risks of Central Clearing in the Repo Market*.

¹⁹As an example, recall that the first central counterparties originated next to grain and coffee exchanges, where *farmers* and *bakers* traded futures. Among many, for references see Kroszner (2006), and Gregory (2014).

7 Appendix

7.1 Proof of Lemma 1

Proof. First, we show that the optimal contract requires positive collateral, meaning that $\omega - c_1^i > 0$. Suppose by contradiction that constraint (3) binds, i.e. $c_1^i = \omega$. From the limited commitment constraint (6) we know that $c_{2,h}^i \geq (1 - \lambda^i)\theta > 0$; therefore the participation (2) is slack. But then, the lender could decrease c_1^i : all constraints would still be satisfied, and her expected utility would increase. This is a contradiction and proves that it must be that $c_1^i < \omega$. Then we conclude that the optimal contract requires positive collateral and constraint (3) is slack.

Next, we show that second period borrowers' consumption in the low state equals zero, i.e. $c_{2,l}^i = 0$. To prove this, first notice that it must be that $x_{2,h}^i \geq x_{2,l}^i$. If not, i.e. if $x_{2,h}^i < x_{2,l}^i$, combining equations (4) and (5) (with equality) we obtain

$$c_{2,h}^i = c_{2,l}^i + \theta + (x_{2,l}^i - x_{2,h}^i) > c_{2,l}^i + \theta > (1 - \lambda^i)\theta$$

Then, the lender could reduce $c_{2,h}^i$ by ϵ , increase $x_{2,h}^i$ by the same amount, increase $c_{2,l}^i$ by $\frac{p}{1-p}\epsilon$, and reduce $x_{2,l}^i$ by the same amount. All constraints would be satisfied, and by concavity of $u(\cdot)$ the lender would increase her expected utility. Now that we established that $x_{2,h}^i \geq x_{2,l}^i$, suppose by contradiction that $c_{2,l}^i > 0$. Then it should be that $x_{2,h}^i = x_{2,l}^i$. If not, i.e. if $x_{2,h}^i > x_{2,l}^i$, the lender could increase $c_{2,h}^i$ by ϵ , reduce $x_{2,h}^i$ by the same amount, reduce $c_{2,l}^i$ by $\frac{p}{1-p}\epsilon$, and increase $x_{2,l}^i$ by the same amount. All constraints would be satisfied, and by concavity of $u(\cdot)$ the lender would increase her expected utility. Since $x_{2,h}^i = x_{2,l}^i$, combining (4) and (5) (with equality) we obtain

$$c_{2,h}^i = c_{2,l}^i + \theta > (1 - \lambda^i)\theta$$

But then the lender could reduce $c_{2,h}^i$ and $c_{2,l}^i$ by ϵ , increase c_1 by $\frac{\epsilon}{\alpha}$, and increase both $x_{2,h}$ and $x_{2,l}$ by the same amount $\frac{\alpha-1}{\alpha}\epsilon$. All constraints would be satisfied and the lender expected

revenues would increase. Therefore it can not be that $c_{2,l}^i > 0$, and we conclude that it should be that $c_{2,l}^i = 0$.

Finally, we show that insurance is incomplete, meaning that $x_{2,h}^i > x_{2,l}^i$. Suppose by contradiction that $x_{2,h}^i = x_{2,l}^i = x$. Combining (4) and (5) (with equality) we obtain

$$c_{2,h}^i = \theta > (1 - \lambda^i)\theta$$

Then the lender can decrease $c_{2,h}^i$ by ϵ , increase c_1^i by $\frac{p\epsilon}{\alpha}$, decrease $x_{2,l}$ by $\frac{p\epsilon}{\alpha}$ and increase $x_{2,h}$ by $\frac{\alpha-p}{p}\epsilon$. For ϵ sufficiently small, the lender's expected utility can be rewritten as

$$\begin{aligned} & pu \left(x + \frac{\alpha-p}{\alpha}\epsilon \right) + (1-p)u \left(x - \frac{p\epsilon}{\alpha} \right) \\ & \approx p \left[u(x) + u'(x)\frac{\alpha-p}{\alpha}\epsilon \right] + (1-p) \left[u(x) - u'(x)\frac{p\epsilon}{\alpha} \right] \\ & = u(x) + u'(x) \left[p\epsilon\frac{\alpha-1}{\alpha} \right] > u(x) \end{aligned}$$

Therefore the lender could increase her expected utility, which proves that the original contract could not be optimal, and concludes the proof. ■

7.2 Proof of Lemma 2

Proof. It is easy to see that both the participation constraint (2) and the limited commitment constraint (6) can not be slack: if this was the case, the lender could increase her revenues just by decreasing $c_{2,h}^i$.

Suppose then that $\omega < \frac{(1-\lambda^i)p\theta}{\alpha}$. Because $c_{2,h}^i \geq (1 - \lambda^i)\theta$ and $c_1^i \geq 0$, the participation constraint (2) is slack. Since both (2) and (6) can not be slack, it must be that (6) binds: $c_{2,h}^i = (1 - \lambda^i)\theta$. Easily, $c_1^i = 0$: if not, the lender could decrease c_1^i , satisfy all constraints, and increase her expected utility. ■

7.3 Proof of Lemma 3

Proof. First, we show that when $\omega > \frac{(1-\lambda^i)p\theta}{\alpha}$, the participation constraint (2) always binds. Suppose by contradiction the participation constraint (2) is slack when $\omega > \frac{(1-\lambda^i)p\theta}{\alpha}$. Then, since both constraints can not be slack, the limited commitment constraint (6) should bind, i.e. $c_{2,h}^i = (1-\lambda^i)\theta$. Then, since $\omega > \frac{(1-\lambda^i)p\theta}{\alpha}$, it must be that $c_1^i > 0$. If instead we had $c_1^i = 0$, then $\alpha c_1^i + p c_{2,h}^i = p(1-\lambda^i)\theta < \alpha\omega$ and the participation constraint (2) would be violated. Then if $\omega > \frac{(1-\lambda^i)p\theta}{\alpha}$, the participation constraint (2) always binds.

Next, we show that equation (11) defines a unique threshold λ^* . Define the function $F(\lambda)$ as

$$F(\lambda) = \frac{u' \left(\frac{(1-\lambda)p\theta}{\alpha} \right)}{u' \left(\theta + (1-\lambda) \frac{p\theta}{\alpha} \left(1 - \frac{\alpha}{p} \right) \right)}$$

Easily $F(0) = 1 < \frac{\alpha-p}{1-p}$ and $F'(\lambda) > 0$. Therefore, if a λ^* exists, this is unique. A necessary and sufficient condition for λ^* to exist is that $\frac{\alpha-p}{1-p} < F(1) = \frac{u'(0)}{u'(0)}$.

Next, given the unique threshold λ^* defined by (11), we show that if $\lambda^i < \lambda^*$, the limited liability constraint (6) binds. Suppose not: $\lambda^i < \lambda^*$ and (6) is slack. Then $c_{2,h}^i > (1-\lambda^i)\theta > (1-\lambda^*)\theta$. Therefore $\eta = 0$ in (10); moreover we know from above that the participation constraint (2) binds. Solving (2) for $c_{2,h}^i$ we obtain $c_{2,h}^i = \frac{\alpha}{p}(\omega - c_1)$, combined with the slack limited commitment constraint (6) gives $\omega - c_1^i > \frac{(1-\lambda^i)p\theta}{\alpha} > \frac{(1-\lambda^*)p\theta}{\alpha}$. From (7), as $\eta = 0$ we have

$$\mu = u'(\omega - c_1^i + \theta - c_{2,h}^i) = u' \left(\theta - (\omega - c_1) \left[1 - \frac{\alpha}{p} \right] \right)$$

Replaced in (8), we obtain

$$\begin{aligned} 0 &\geq (\alpha - p)u' \left(\theta - (\omega - c_1) \left[1 - \frac{\alpha}{p} \right] \right) - (1-p)u'(\omega - c_1) \\ &> (\alpha - p)u' \left(\theta - \frac{(1-\lambda^*)p\theta}{\alpha} \left[\frac{\alpha - p}{p} \right] \right) - (1-p)u' \left(\frac{(1-\lambda^*)p\theta}{\alpha} \right) = 0 \end{aligned}$$

which is a contradiction. Then, we conclude that if $\lambda^i < \lambda^*$, the limited commitment con-

straint (6) should bind. The consumption of the lender is

$$\begin{aligned}x_{2,h}^i &= \lambda^i \theta + \frac{(1 - \lambda^i)p\theta}{\alpha} \\x_{2,l}^i &= \frac{(1 - \lambda^i)p\theta}{\alpha}\end{aligned}$$

Next, we show that if $\lambda^i > \lambda^*$, the limited commitment constraint (6) is slack. Suppose by contradiction that $\lambda^i > \lambda^*$ and the limited commitment constraint (6) binds. Then, $c_{2,h}^i = (1 - \lambda^i)\theta$ and, as the participation constraint (2) binds as well, $c_1^i = \omega - \frac{(1 - \lambda^i)p\theta}{\alpha} > 0$. From (8) we have

$$\mu = \frac{pu' \left(\lambda^i \theta + \frac{(1 - \lambda^i)p\theta}{\alpha} \right)}{\alpha} + \frac{(1 - p)u' \left(\frac{(1 - \lambda^i)p\theta}{\alpha} \right)}{\alpha}$$

which replaced in (7) gives

$$\eta = \frac{p}{\alpha} \left[(\alpha - p)u' \left(\lambda^i \theta + \frac{(1 - \lambda^i)p\theta}{\alpha} \right) - (1 - p)u' \left(\frac{(1 - \lambda^i)p\theta}{\alpha} \right) \right] < 0$$

where the inequality follows since $\lambda^i > \lambda^*$. Therefore, if $\lambda^i > \lambda^*$, the limited commitment constraint (6) is slack.

Finally, we have to determine for $\lambda^i > \lambda^*$ whether $c_1^i > 0$ or $c_1^i = 0$. Since (6) is slack, therefore $\eta = 0$, and (2) binds, therefore $c_{2,h}^i = \frac{\alpha(\omega - c_1^i)}{p}$, condition (7) gives

$$\mu = u' \left(\theta - (\omega - c_1^i) \frac{\alpha - p}{p} \right)$$

replaced in (8) gives

$$(\alpha - p)u' \left(\theta - (\omega - c_1^i) \frac{\alpha - p}{p} \right) - (1 - p)u'(\omega - c_1^i) \leq 0$$

with equality if $c_1^i > 0$. Then, by the definition of λ^* in (11), it is clear that $c_1^i > 0$ if and only if $\omega > \frac{(1 - \lambda^*)p\theta}{\alpha}$, and $c_1^i = 0$ if $\omega < \frac{(1 - \lambda^*)p\theta}{\alpha}$. This concludes the proof of Lemma 2. ■

7.4 If $C_{2h}^H > (1 - \lambda^L)\theta$ in problem $(P0^{FI})$, then central clearing with screening can not be optimal

Proof. Let (X_2^H, X_2^L) , $(C_1, C_{2,s}^i)_{i=L,H,s=h,l}$ be the solution to problem $(P0^{FI})$ and suppose $C_{2h}^H > (1 - \lambda^L)\theta$. Consider now the contract with central clearing, no monitoring, and pooling over λ^L defined as $\hat{X}_2 = qX_2^H + (1 - q)X_2^L$, $\hat{C}_{2,s} = qC_{2,s}^H + (1 - q)C_{2,s}^L$, and $\hat{C}_1 = qC_1^H + (1 - q)C_1^L$. Easily such constraints (50)-(53) in problem (P^L) . Concavity of $u(\cdot)$ gives $u(\hat{X}_2) \geq qu(X_2^H) + (1 - q)u(X_2^L) = V^{FI} + \gamma$, so it is strictly better than the original contract with monitoring. ■

7.5 Proof of Lemma 4

Proof. First we show the only if direction. Suppose that $(C_1^i, C_{2h}^i, C_{2l}^i, w^i)_{i=L,H}$ is the solution to problem (\hat{P}^{FI}) , but either $(C_1^i, C_{2h}^i, C_{2l}^i)_{i=L,H}$ does not solve $(\hat{P}b^{FI})$, or for Ω^* the solution to $(\hat{P}b^{FI})$, (w_H, w_L) solve $(\hat{P}a_{\Omega^*}^{FI})$.

If $(C_1^i, C_{2h}^i, C_{2l}^i)_{i=L,H}$ does not solve $(\hat{P}b^{FI})$, let $(C_1^{i'}, C_{2h}^{i'}, C_{2l}^{i'})_{i=L,H}$ be the solution to $(\hat{P}b^{FI})$. From problem $(\hat{P}b^{FI})$, it must be that for some i , either $C_1^{i'} < C_1^i$, or $C_{2h}^{i'} < C_{2h}^i$, or $C_{2l}^{i'} < C_{2l}^i$. Suppose w.l.o.g. that $C_1^{H'} < C_1^H$. Then, in problem (\hat{P}^{FI}) consider a new contract $(C_1^{i''}, C_{2h}^{i''}, C_{2l}^{i''}, w^{i''})_{i=L,H}$ where $C_{2h}^{i''} = C_{2h}^i$, $C_{2l}^{i''} = C_{2l}^i$, $C_1^{i''} = C_1^i - \epsilon$. If $w^L > [q + (1 - q)(1 - p)]w^H$, then choose $w^{H''}$ to solve $u^{-1}(w^{H''}) = u^{-1}(w^H) + \epsilon$; if instead $w^L < [q + (1 - q)(1 - p)]w^H$, choose $w^{L''}$ to solve $u^{-1}(w^{L''}) = u^{-1}(w^L) + \frac{q}{1-q}\epsilon$. In both cases, it is easy to show that $(C_1^{i''}, C_{2h}^{i''}, C_{2l}^{i''}, w^{i''})_{i=L,H}$ satisfies constraints (25)-(29) in problem (\hat{P}^{FI}) , and $qw^{H''} + (1 - q)w^{L''} > qw^H + (1 - q)w^L$, that contradicts optimality of the original contract in problem (\hat{P}^{FI}) . If instead $w^L = [q + (1 - q)(1 - p)]w^H$, then choose $w^{H''}$ and $w^{L''}$ to solve $u^{-1}(w^{H''}) = u^{-1}(w^H) + q\epsilon$, and $u^{-1}(w^{L''}) = u^{-1}(w^L) + q\epsilon$. It is easy to show that $w^{L''} > [q + (1 - q)(1 - p)]w^{H''}$, that $(C_1^{i''}, C_{2h}^{i''}, C_{2l}^{i''}, w^{i''})_{i=L,H}$ satisfies constraints (25)-(29) in problem (\hat{P}^{FI}) , and $qw^{H''} + (1 - q)w^{L''} > qw^H + (1 - q)w^L$, which contradicts again optimality of the original contract in problem (\hat{P}^{FI}) .

If instead $(C_1^i, C_{2h}^i, C_{2l}^i, w^i)_{i=L,H}$ solve problem (\hat{P}^{FI}) , but for Ω^* the solution to $(\hat{P}b^{FI})$, (w_H, w_L) does not solve $(\hat{P}a_{\Omega^*}^{FI})$, let $(w^{H'}, w^{L'})$ solve $(\hat{P}a_{\Omega^*}^{FI})$. It is straightforward to show

that $(C_1^i, C_{2h}^i, C_{2l}^i, w^i)_{i=L,H}$ satisfies constraints (25)-(29) in problem (\hat{P}^{FI}) , and $qw^{H'} + (1-q)w^{L'} > qw^H + (1-q)w^L$, which contradicts optimality of the original contract in problem (\hat{P}^{FI}) .

Next, we show the if direction. Let $(C_1^i, C_{2h}^i, C_{2l}^i)_{i=L,H}$ solve $(\hat{P}b^{FI})$, and for Ω^* the solution to $(\hat{P}b^{FI})$, (w^H, w^L) solve $(\hat{P}a_{\Omega^*}^{FI})$. Suppose by contradiction that $(C_1^i, C_{2h}^i, C_{2l}^i, w^i)_{i=L,H}$ does not solve problem (\hat{P}^{FI}) . Let $(C_1^{i'}, C_{2h}^{i'}, C_{2l}^{i'}, w^{i'})$ be the solution to (\hat{P}^{FI}) . Then easily it must be that either $C_1^{i'} \neq C_1^i$, or $C_{2h}^{i'} \neq C_{2h}^i$, or $C_{2l}^{i'} \neq C_{2l}^i$: if not it must be $w^H = w^{H'}$ and $w^L = w^{L'}$ by comparing $(\hat{P}a_{\Omega^*}^{FI})$ with (\hat{P}^{FI}) . By definition of problem $(\hat{P}b^{FI})$, then it should be that either $C_1^{i'} > C_1^i$, or $C_{2h}^{i'} > C_{2h}^i$, or $C_{2l}^{i'} > C_{2l}^i$. Suppose, w.l.o.g. that $C_1^{H'} > C_1^H$. Then, following the same argument as in the only if part, we can prove that $(C_1^{i'}, C_{2h}^{i'}, C_{2l}^{i'}, w^{i'})$ can not be the solution to (\hat{P}^{FI}) , which is a contradiction. ■

7.6 Proof of Lemma 5

Proof. Let $(w^H, w^L) \in \mathfrak{R}_+^2$ satisfy equations (31), (32), and (33). Define X as

$$qu^{-1}(w^H) + (1-q)u^{-1}(w^L) = X$$

and $(w^{H'}, w^{L'})$ as the unique solution to

$$\begin{aligned} [q + (1-q)(1-p)]w^{H'} &= w^{L'} \\ qu^{-1}(w^{H'}) + (1-q)u^{-1}(w^{L'}) &= X \end{aligned}$$

We want to show that $(w^{H'}, w^{L'})$ satisfy equations (34), (35), (36), and (37). Notice that equation (34) and equation (35) are satisfied by construction.

Now, suppose by contradiction that equation (36) is violated. Therefore

$$\begin{aligned} w^{H'} &< w^{L'} + \frac{\gamma}{q} \\ w^{L'} &= [q + (1-q)(1-p)]w^{H'} \end{aligned}$$

It is easy to show that the two conditions can hold only if $w^{L'} < \frac{q+(1-q)(1-p)}{pq(1-q)}$, therefore $w^{H'} = \frac{w^{L'}}{q+(1-q)(1-p)} < \frac{\gamma}{pq(1-q)}$. Since u^{-1} is increasing, by the definition of $w^{H'}$ and $w^{L'}$ we have

$$X = qu^{-1}(w^{H'}) + (1-q)u^{-1}(w^{L'}) < qu^{-1}\left(\frac{\gamma}{pq(1-q)}\right) + (1-q)u^{-1}\left(\frac{q+(1-q)(1-p)}{pq(1-q)}\gamma\right) \quad (66)$$

It is easy to show that equations (32) and (33) can hold only if $w^H \geq \frac{\gamma}{pq(1-q)}$ and $w^L \geq \frac{q+(1-q)(1-p)}{pq(1-q)}\gamma$. Then, since u^{-1} is increasing, from the definition of X we have

$$X \geq qu^{-1}\left(\frac{\gamma}{pq(1-q)}\right) + (1-q)u^{-1}\left(\frac{q+(1-q)(1-p)}{pq(1-q)}\gamma\right)$$

that contradicts equation (66). Therefore equation (36) can not be violated.

Finally notice that we can rewrite

$$\begin{aligned} qw^{H'} + (1-q)w^{L'} &= q \left(w^H + \int_{w^L}^{w^{L'}} \left[-u' \left(\frac{X - (1-q)u^{-1}(s)}{q} \right) \frac{1-q}{q} \frac{1}{u'(s)} \right] ds \right) \\ &\quad + (1-q) \left(w^L + \int_{w^L}^{w^{L'}} 1 ds \right) \\ &= qw^H + (1-q)w^L + (1-q) \int_{w^L}^{w^{L'}} \left[1 - \frac{u' \left(\frac{X - (1-q)u^{-1}(s)}{q} \right)}{u'(s)} \right] ds \\ &> qw^H + (1-q)w^L \end{aligned}$$

where the last inequality follows from concavity of u together with the fact that $\frac{X - (1-q)u^{-1}(s)}{q} > s$ for all $s \in [w^L, w^{L'}]$. Therefore equation (37) is as well satisfied. ■

7.7 Proof of Lemma 6

Proof. The smallest values of w^H and w^L that jointly satisfy (39) and (40) are $w^H = \frac{\gamma}{pq(1-q)}$ and $w^L = \frac{\gamma[q+(1-q)(1-p)]}{pq(1-q)}$. Then constraint (38) can be satisfied jointly with (39) and (40) only if $\Omega \geq \hat{\Omega}$ as defined above.

Easily, when $\Omega \geq \hat{\Omega}$ both (39) and (40) have to bind. If (39) does not bind, we can increase w^H and w^L by ϵ and all constraints are still satisfied. If (40) is not binding, we can construct a mean-preserving contraction on $u^{-1}(w^H)$ and $u^{-1}(w^L)$ so that (39) is unaffected, but by convexity of $u^{-1}(\cdot)$ the objective function strictly increases. ■

7.8 Proof of Lemma 7

Proof. The solution is the consequence of linearity of the objective function, and $\alpha > 1$. ■

7.9 Proof of Lemma 9

Proof. Suppose by contradiction that the optimal contracts $\{(C_1^i, C_{2,h}^i, C_{2,l}^i), X_2\}$ recommend $\Sigma^H = 1$. Then, by (48) it must be that λ^H -borrowers prefer the strategy $(\hat{m}, \hat{\sigma}) = (\lambda^H, 1)$ to the strategy $(\hat{m}, \hat{\sigma}) = (\lambda^L, 0)$:

$$\alpha C_1^H + p(1 - \lambda^H)\theta + (1 - p)C_{2,l}^H \geq \alpha C_1^L + pC_{2,h}^L + (1 - p)C_{2,l}^L \quad (67)$$

Suppose first that the contracts recommend $\Sigma^L = 0$: from (48) λ^L -borrowers need to prefer the strategy $(\hat{m}, \hat{\sigma}) = (\lambda^L, 0)$ over the strategy $(\hat{m}, \hat{\sigma}) = (\lambda^L, 1)$:

$$\alpha C_1^L + C_{2,h}^L + (1 - p)C_{2,l}^L \geq \alpha C_1^H + p(1 - \lambda^L)\theta + (1 - p)C_{2,l}^H$$

Combining this expression with (67) we obtain a contradiction. Therefore, it is not possible for the contracts to recommend $\Sigma^L = 0$.

Suppose then the the optimal contracts $\{(C_1^i, C_{2,h}^i, C_{2,l}^i), X_2\}$ recommend $\Sigma^L = 1$. Define a new contract $\{(\tilde{C}_1^i, \tilde{C}_{2,h}^i, \tilde{C}_{2,l}^i), \tilde{X}_2\}$ as $\tilde{X}_2 = X_2$, $\tilde{C}_{2,h}^H = (1 - \lambda^H)\theta$, $\tilde{C}_{2,s}^i = C_{2,s}^i$ if either $i \neq H$ and $s \neq h$, $\tilde{C}_1^i = C_1$ for $i = L, H$. Let such a contract recommend $\tilde{\Sigma}^H = 0$, $\tilde{\Sigma}^L = 1$. It is easy to check that all constraints in problem (44) - (48) are satisfied, and as X_2 did not change the new contract is payoff equivalent to the original (optimal) one, which concludes the proof. ■

7.10 Proof of Lemma 10

Proof. *i)* Suppose not. Then $C_1 = \omega$ and the participation constraint (50) must be slack if $C_{2,h}$ satisfies the limited commitment constraint (51). Consider then the allocation defined by $\hat{C}_1 = C_1 - \varepsilon$ for $\varepsilon > 0$ arbitrarily small, and $\hat{X}_2 = X_2 + \alpha\varepsilon$. This allocation is still in the constraint set of problem (P^L) and yields higher value of the objective.

ii) Suppose not. Consider then the allocation defined by $\hat{X}_2 = X_2 + \varepsilon$, for $\varepsilon > 0$ arbitrarily small so that the resource constraint at $t = 2$, (53), is still satisfied. This allocation is still in the constraint set of problem (P^L) and yields higher value of the objective.

iii) Suppose not. Then $C_{2,l} > 0$: consider the allocation defined by $\hat{C}_{2,l} = C_{2,l} - \varepsilon$, $\hat{C}_1 = C_1 + \frac{\varepsilon}{\alpha}$ and $\hat{X}_2 = X_2 + \varepsilon(1 - \frac{1}{\alpha})$. Because $\alpha > 1$ then $\hat{X}_2 > X_2$. Therefore this allocation is still in the constraint set to problem (P^L) and yields higher value of the objective. ■

7.11 Proof of Lemma 11

Proof. Consider problem (44) - (48). In (48), the recommended default decision $\Sigma^H = 0$ and $\Sigma^L = 0$ require $C_{2,h}^H \geq (1 - \lambda^H)\theta$ and $C_{2,h}^L \geq (1 - \lambda^L)\theta$ respectively. Constraint (48) for λ^H -borrowers can be rewritten as

$$C_{2,h}^H \geq (1 - \lambda^H)\theta \quad (68)$$

$$\alpha C_1^H + p C_{2,h}^H + (1 - p) C_{2,l}^H \geq \alpha C_1^L + p C_{2,h}^L + (1 - p) C_{2,l}^L \quad (69)$$

whereas constraint (48) for λ^L -borrowers becomes

$$C_{2,h}^L \geq (1 - \lambda^L)\theta \quad (70)$$

$$\alpha C_1^L + p(1 - \lambda^L)\theta + (1 - p) C_{2,l}^L \geq \alpha C_1^H + p \max\{(1 - \lambda^L)\theta, C_{2,h}^H\} + (1 - p) C_{2,l}^H \quad (71)$$

Step 1: The optimal contract should satisfy $C_{2,h}^H \geq (1 - \lambda^L)\theta$. Then (68) can be ignored. Furthermore both (71) and (69) bind.

Combine (71) with (69):

$$\begin{aligned}
\alpha C_1^H + pC_{2,h}^H + (1-p)C_{2,l}^H &\geq \alpha C_1^L + pC_{2,h}^L + (1-p)C_{2,l}^L \\
&\geq \alpha C_1^H + p \max\{(1-\lambda^L)\theta, C_{2,h}^H\} + (1-p)C_{2,l}^H \\
&\geq \alpha C_1^H + pC_{2,h}^H + (1-p)C_{2,l}^H
\end{aligned}$$

Then all weak inequalities have to hold with equality, $C_{2,h}^H \geq (1-\lambda^L)\theta$, and both (71) and (69) bind.

Step 3: W.l.o.g we can ignore the participation constraint (45) of the λ^H borrower.

It follows immediately from the previous step.

Step 4: We have $C_{2,l}^L = 0$.

Suppose not: $C_{2,l}^L > 0$. Then it must be $C_1^L = \omega$. If not we could reduce $C_{2,l}^L$ by ϵ , increase C_1^L by $\frac{(1-p)\epsilon}{\alpha}$, and increase X_2 by $(1-q)(1-p)\epsilon[1 - \frac{1}{\alpha}] > 0$. The new contract would be feasible and expected utility would increase. Then $C_1^L = \omega$, and therefore as $C_{2,l}^L > 0$ and $C_{2,h}^L \geq (1-\lambda^L)\theta$, the participation constraint (45) of λ^L borrowers can be ignored as well. Moreover, it must be $C_{2,h}^H = (1-\lambda^L)\theta$, otherwise we could reduce $C_{2,l}^L$ by ϵ and $C_{2,h}^H$ by $\frac{(1-p)\epsilon}{p}$ and increase X_2 by $p\epsilon$. The new contract would still satisfy all constraints and the expected utility would increase. Similarly it should be $C_{2,l}^H = 0$. If not we could reduce $C_{2,l}^L$ and $C_{2,l}^H$ by ϵ , and increase X_2 by $(1-p)\epsilon$. Finally, it should be $C_1^H = 0$, otherwise we could reduce $C_{2,l}^L$ by ϵ , reduce C_1^H by $\frac{(1-p)\epsilon}{\alpha}$ and increase X_2 by $(1-p)\epsilon[\frac{1}{\alpha} + (1-q)]$. Combing $C_1^H = C_{2,l}^H = C_{2,l}^L = 0$, $C_{1,h}^H = (1-\lambda^L)\theta$, $C_1^L = \omega$, we obtain that the binding (48) becomes

$$\alpha\omega + pC_{2,h}^H + (1-p)C_{2,l}^L = (1-\lambda^L)\theta$$

which can never be satisfied for $C_{2,l}^L > 0$ and $C_{2,h}^L \geq (1-\lambda^L)\theta$, which is a contradiction.

Step 5: We have $C_{2,l}^H = 0$.

Suppose not: suppose $C_{2,l}^H > 0$. Then it should be $C_1^H = \omega$, otherwise we could educe $C_{2,l}^H$ by ϵ , increase C_1^H by $\frac{(1-p)\epsilon}{\alpha}$, and increase X_2 by $q(1-p)\epsilon[1 - \frac{1}{\alpha}] > 0$. Moreover the participation constraint (45) of λ^L borrowers should bind: if not following the same arguments of the previous step it should be $C_1^L = 0$ and $C_{2,h}^L = (1 - \lambda^L)\theta$. But the participation constraint (45) of λ^L borrowers and the binding (48) would give

$$\begin{aligned} (1 - \lambda^L)p\theta &= \alpha C_1^L + pC_{2,h}^L + (1 - p)C_{2,l}^L = \alpha C_1^H + pC_{2,h}^H + (1 - p)C_{2,l}^H \\ &= \alpha\omega + pC_{2,h}^H + (1 - p)C_{2,l}^L > (1 - \lambda^L)p\theta \end{aligned}$$

which is a contradiction. Then it should be

$$\alpha C_1^L + pC_{2,h}^L = \alpha\omega$$

This implies that $C_1^L < \omega$, as $C_{2,h}^L > 0$. Then (45) of λ^L borrowers and (48) give

$$\alpha\omega = \alpha C_1^L + pC_{2,h}^L = \alpha\omega + pC_{2,h}^H > \alpha\omega$$

which is a contradiction.

Step 6: $C_{2,h}^H = C_{2,h}^L = (1 - \lambda^L)\theta$.

Suppose $C_{2,h}^i > (1 - \lambda^L)\theta$. Reduce $C_{2,h}^i$ by ϵ , increase C_1^i by $\frac{p\epsilon}{\alpha}$ and X_2 by $q_i p \epsilon [1 - \frac{1}{\alpha}]$, and the expected utility would increase.

Step 7: $C_1^H = C_1^L$.

Follows from (48) holding with equality.

Step 8: The optimal contract that induces no borrower to strategically default in equilibrium is $C_{2,l}^i = 0$, $C_{2,h}^i = (1 - \lambda^L)\theta$, $C_1^i = \min\left\{0, \omega - \frac{(1 - \lambda^L)}{\alpha}\right\}$, and $(C_{2,h}^L, C_1^L, C_{2,l}^L, X_2)$ solve

problem (P^L).

The conclusion follows from comparing the residual problem with (P^L). ■

7.12 Proof of Lemma 12

Proof. From linearity of the objective, (51) always binds. Then whether (50) binds or not depends on whether $\omega \geq \frac{(1-\lambda^L)p\theta}{\alpha}$ or not. ■

7.13 Proof of Lemma 13

Proof. The proof is identical to the one of Lemma 10. ■

7.14 Proof of Lemma 14

Proof. Consider problem (44) - (48). In (48), the recommended default decision $\Sigma^H = 0$ and $\Sigma^L = 1$ require $C_{2,h}^H \geq (1 - \lambda^H)\theta$ and $C_{2,h}^L < (1 - \lambda^L)\theta$ respectively. Constraint (48) for λ^H -borrowers can be rewritten as

$$C_{2,h}^H \geq (1 - \lambda^H)\theta \quad (72)$$

$$\alpha C_1^H + p C_{2,h}^H + (1 - p) C_{2,l}^H \geq \alpha C_1^L + p \max\{(1 - \lambda^H)\theta, C_{2,h}^L\} + (1 - p) C_{2,l}^L \quad (73)$$

whereas constraint (48) for λ^L -borrowers becomes

$$C_{2,h}^L \leq (1 - \lambda^L)\theta \quad (74)$$

$$\alpha C_1^L + p(1 - \lambda^L)\theta + (1 - p) C_{2,l}^L \geq \alpha C_1^H + p \max\{(1 - \lambda^L)\theta, C_{2,h}^H\} + (1 - p) C_{2,l}^H \quad (75)$$

Step 1: W.l.o.g. we can choose $C_{2,h}^L = (1 - \lambda^L)\theta$, and ignore constraint (74).

This choice satisfies (74) and relaxes (75) as much as possible. Since $\Sigma^L = 1$ is the recommended (i.e. incentive compatible) default choice, $C_{2,h}^L$ does not appear in any other constraint. This means that we can assume $C_{2,h}^L = (1 - \lambda^L)\theta$.

Step 2: We can ignore the participation constraint of λ^L -borrowers.

From (75) and the participation constraint of λ^H -borrowers,

$$\alpha C_1^L + p(1 - \lambda^L)\theta + (1 - p)C_{2,l}^L \geq \alpha C_1^H + pC_{2,h}^H + (1 - p)C_{2,l}^H \geq \alpha\omega$$

Step 3: The optimal contract requires $C_{2,h}^H \leq (1 - \lambda^L)\theta$.

Suppose by contradiction the optimal contracts $\{(C_1^i, C_{2,h}^i, C_{2,l}^i), X_2\}$ satisfies $C_{2,h}^H > (1 - \lambda^L)\theta > (1 - \lambda^H)\theta$. Then we can ignore (72). Moreover it needs to be that $C_1^H = \omega$: if not, the CCP could reduce $C_{2,h}^H$ by ϵ , increase C_1^H by $\frac{p}{\alpha}\epsilon$, and increase X_2 by $\frac{\alpha-1}{\alpha}qp\epsilon > 0$. All constraints are still satisfied but the expected utility of lenders increases. But then, since $C_1^H = \omega$, we can also ignore the participation constraint of λ^H -borrowers. From constraint (73), we can ignore (75). Therefore the only constraints left are (73), the resource constraint (46) for $i = L$, and the second-period resource constraint (47). Note that (73) should bind or the CCP could reduce $C_{2,h}^H$ and increase X_2 accordingly, without violating any constraint:

$$\alpha\omega + pC_{2,h}^H + (1 - p)C_{2,l}^H = \alpha C_1^L + p(1 - \lambda^H)\theta + (1 - p)C_{2,l}^L \quad (76)$$

From this expression and (46) it needs to be $C_{2,l}^L > C_{2,l}^H \geq 0$. Then it has to be $C_{2,l}^H = 0$, otherwise we could decrease both $C_{2,l}^L$ and $C_{2,l}^H$ by ϵ , and increase X_2 by $(1 - p)\epsilon$ it needs to be $C_{2,l}^L > C_{2,l}^H \geq 0$. Then it has to be $C_{2,l}^H = 0$, otherwise we could decrease both $C_{2,l}^L$ and $C_{2,l}^H$ by ϵ , and increase X_2 by $(1 - p)\epsilon$. Replacing $C_{2,l}^H = 0$ we obtain that

$$(1 - p)C_{2,l}^L = \alpha(\omega - C_1^L) + p[C_{2,h} - (1 - \lambda^H)\theta] > 0$$

But then it has to be that $C_1^L = \omega$: if $C_1^L < \omega$, the CCP can decrease $C_{2,l}^L$ by ϵ and increase C_1^L by $\frac{p}{\alpha}\epsilon$, and increase X_2 by $\frac{\alpha-1}{\alpha}(1 - q)p\epsilon > 0$. All constraints are still satisfied but the expected utility of lenders increases. Moreover it needs to be that $C_{2,l}^L = 0$. If not, the CCP could reduce C_1^H by ϵ , $C_{2,l}^L$ by $\frac{p}{1-p}\epsilon$, and increase X_2 by $p\epsilon$. All constraints are still satisfied but the expected utility of lenders strictly increase. But then, equation (76) becomes

$$(1 - \lambda^L)p\theta < pC_{2,h}^H = p(1 - \lambda^H)\theta$$

which is not possible. This proves that it must be that $C_{2,h}^H \leq (1 - \lambda^L)\theta$. Replacing this value in (75), the latter becomes

$$\alpha C_1^L + (1 - p)C_{2,l}^L \geq \alpha C_1^H + (1 - p)C_{2,l}^H$$

Step 4: At the optimal solution, equation (75) holds with equality: $\alpha C_1^L + (1 - p)C_{2,l}^L = \alpha C_1^H + (1 - p)C_{2,l}^H$.

Suppose not: suppose that (75) is slack. The only active constraints are then the resource constraint in $t = 1$, (46) the resource constraint in $t = 2$, (47), and the incentive compatibility constraints (72) and (73). But then it should easily be that it $C_1^L = C_{2,l}^L = 0$. As a result, (75) can only hold if $C_1^H = C_{2,l}^H = 0$, and equation (75) holds with equality.

Step 5: Constraint (73) can be ignored.

Use the fact that (75) binds and (74), we obtain

$$\begin{aligned} \alpha C_1^H + pC_{2,h}^H + (1 - p)C_{2,l}^H &= \alpha C_1^L + pC_{2,h}^H + (1 - p)C_{2,l}^L \\ &\geq \alpha C_1^L + p(1 - \lambda^H)\theta + (1 - p)C_{2,l}^L \end{aligned}$$

Step 6: It is optimal to choose $C_{2,l}^H = C_{2,l}^L = 0$.

Suppose not: suppose w.l.o.g. that $C_{2,l}^H \geq C_{2,l}^L \geq 0$ with one inequality holding as a strict inequality. If $C_{2,l}^H = C_{2,l}^L > 0$, then we could decrease both by ϵ , increase X_2 by $(1 - p)\epsilon$, satisfying all the relevant constraints and increasing the expected utility. If instead $C_{2,l}^H > C_{2,l}^L = 0$, it has to be $0 \leq C_1^H < C_1^L$. But then we could reduce $C_{2,l}^H$ by ϵ , reduce C_1^L by $\frac{(1-p)\epsilon}{\alpha}$, and increase X_2 by $(1 - p)\epsilon[q + \frac{1-q}{\alpha}]$. All constraints would be satisfied, and the expected utility would increase.

Step 7: It is optimal to choose $C_1^H = C_1^L$.

It follows immediately by the binding (75) once we replace $C_{2,l}^H = C_{2,l}^L = 0$.

$$\alpha C_1^H = \alpha C_1^L$$

Step 8: The optimal contract that induces λ^L types to strategically default in equilibrium is $C_{2,h}^L = (1 - \lambda^H)\theta$, $C_{2,l}^H = C_{2,l}^L = 0$, $C_1^L = C_1^H$, and $(C_{2,h}^H, C_1^H, X_2)$ that solve problem (P^H) . Rewriting the problem for $(C_{2,h}^H, C_1^H, X_2)$ with the relevant constraints, we obtain:

$$\begin{aligned} & \max_{(X_2, C_1^H, C_{2h}^H)} u(X_2) \\ & \text{s.t.} \quad \alpha C_1^H + p C_{2h}^H \geq \alpha \omega \\ & \quad (1 - \lambda^L)\theta \geq C_{2h}^H \geq (1 - \lambda^H)\theta \\ & \quad 0 \leq C_1^H \leq \omega \\ & \quad X_2 + qp C_{2h}^H + (1 - q)p(1 - \lambda^L)\theta \leq \omega - C_1^H + p\theta \end{aligned}$$

From Lemma 13 we have $C_{2,l} = 0$ in problem (P^H) , which completes the proof of Lemma 14.

■

7.15 Proof of Lemma 15

Proof. Because the resource constraint in $t = 2$ binds and in $t = 1$ is slack, we can rewrite:

$$\begin{aligned} V^{CCP, \lambda^H} &= \max u[\omega - C_1 + p\theta - qpC_{2h} - (1 - q)p(1 - \lambda^L)\theta] \\ & \text{s.t.} \quad \alpha C_1 + pC_{2h} + (1 - p)C_{2l} \geq \alpha \omega \\ & \quad C_{2h} \geq (1 - \lambda^H)\theta \\ & \quad C_{2h} \leq (1 - \lambda^L)\theta \\ & \quad C_1 \geq 0 \end{aligned}$$

1. Suppose first that the participation constraint binds. Then $C_1 = \omega - \frac{pC_{2h}}{\alpha}$. Then in the

objective we have

$$\begin{aligned} \max \quad & u \left(p\theta + \frac{pC_{2h}}{\alpha} - qpC_{2h} - (1-q)p(1-\lambda^L)\theta \right) \\ \text{s.t.} \quad & \omega - \frac{pC_{2h}}{\alpha} \geq 0 \\ & (1-\lambda^L)\theta \geq C_{2h} \geq (1-\lambda^H)\theta \end{aligned}$$

(a) If $q \geq \frac{1}{\alpha}$, the objective is decreasing in C_{2h} , so the solution is $C_{2h} = (1-\lambda^H)\theta$.

This can be a solution only if $\omega \geq \frac{(1-\lambda^H)p\theta}{\alpha}$.

(b) If $q < \frac{1}{\alpha}$, then the solution is increasing in C_{2h} , so the solution is $C_{2h} = \min \left\{ (1-\lambda^L)\theta, \frac{\alpha\omega}{p} \right\}$

2. Suppose now that the participation constraint is slack. Then easily $C_{2h} = (1-\lambda^H)\theta$ and $C_1 = 0$. This can be a solution if $\omega < \frac{(1-\lambda^H)p\theta}{\alpha}$.

■

7.16 Proof of Lemma 16

Proof. Let us consider when pooling over λ^L can be an equilibrium: $V^{CCP,\lambda^L} \geq V^{CCP,\lambda^H}$.

If $p(1-\lambda^L)\theta \leq \alpha\omega$ and $q\alpha \geq 1$, $V^{CCP,\lambda^L} \geq V^{CCP,\lambda^H}$ if and only if:

$$\begin{aligned} u \left(\frac{(1-\lambda^L)p\theta}{\alpha} + p\theta\lambda^L \right) &\geq u \left(\frac{(1-\lambda^H)p\theta}{\alpha} + p\theta [q\lambda^H + (1-q)\lambda^L] \right) \\ \frac{(\lambda^H - \lambda^L)p\theta}{\alpha} &\geq p\theta [q\lambda^H + (1-q)\lambda^L - \lambda^L] \\ 1 &\geq \alpha q \end{aligned}$$

which is a contradiction, so $V^{CCP,\lambda^H} \geq V^{CCP,\lambda^L}$.

If $p(1-\lambda^L)\theta \leq \alpha\omega$ and $q\alpha < 1$, $V^{CCP,\lambda^H} = V^{CCP,\lambda^L}$. Without loss of generality we say it is optimal to pool over λ^L .

If $p(1-\lambda^H)\theta \leq \alpha\omega < p(1-\lambda^L)\theta$ and $q \geq \frac{1}{\alpha}$ then $V^{CCP,\lambda^L} \geq V^{CCP,\lambda^H}$ if and only if:

$$u(\omega + p\theta\lambda^L) \geq u \left(\frac{(1-\lambda^H)p\theta}{\alpha} + p\theta [q\lambda^H + (1-q)\lambda^L] \right)$$

$$\begin{aligned}
\omega &\geq \frac{(1-\lambda^H)p\theta}{\alpha} + p\theta q(\lambda^H - \lambda^L) \\
&\geq \frac{(1-\lambda^H)p\theta}{\alpha} + \frac{p\theta}{\alpha}(\lambda^H - \lambda^L) = \frac{(1-\lambda^L)p\theta}{\alpha}
\end{aligned}$$

So it is never possible, and we have $V^{CCP,\lambda^H} \geq V^{CCP,\lambda^L}$.

If $p(1-\lambda^H)\theta \leq \alpha\omega < p(1-\lambda^L)\theta$ and $q < \frac{1}{\alpha}$ then $V^{CCP,\lambda^L} \geq V^{CCP,\lambda^H}$ if and only if:

$$\begin{aligned}
u(\omega + p\theta\lambda^L) &\geq u\left(\frac{(1-\lambda^H)p\theta}{\alpha} + p\theta[q\lambda^H + (1-q)\lambda^L] + (1-q\alpha)\left[\omega - \frac{(1-\lambda^H)p\theta}{\alpha}\right]\right) \\
\omega + p\theta\lambda^L &\geq \omega(1-q\alpha) + p\theta - (1-q)(1-\lambda^L)p\theta \\
0 &\geq p\theta(1-\lambda^L) - \alpha\omega > 0
\end{aligned}$$

Which is a contradiction, so it is never possible, and we have $V^{CCP,\lambda^H} \geq V^{CCP,\lambda^L}$.

If $\alpha\omega < p(1-\lambda^H)\theta$ then $V^{CCP,\lambda^L} \geq V^{CCP,\lambda^H}$ if and only if:

$$u(\omega + p\theta\lambda^L) \geq u(\omega + p\theta[q\lambda^H + (1-q)\lambda^L])$$

but this is never possible.

We can summarize the equilibrium CCP clearing conditional on no info acquisition:

1. $\omega < \frac{(1-\lambda^L)p\theta}{\alpha} \implies$ pooling over λ^H
2. $\omega \geq \frac{(1-\lambda^L)p\theta}{\alpha} \implies \begin{cases} 1 < \alpha q \implies \text{pooling over } \lambda^H \\ 1 \geq \alpha q \implies \text{pooling over } \lambda^L \end{cases}$

■

7.17 Proof of Lemma 17

Proof. Let $(\Sigma^i, x_{2,h}^{i,1}, x_{2,h}^{i,0}, x_{2,l}^i, c_1^i, c_{2,h}^i, c_{2,l}^i)_{i=L,H}$, be the optimal contract with bilateral clearing and no information acquisition. Define then the contracts with CCP clearing $(X_2^{i,1}, X_2^{i,0})$ and $(\Sigma_i, C_1^i, C_{2,s}^i)$ as Σ_i the same recommended default decision as in the contract with bilat-

eral clearing, as well as $C_1^i = c_1^i$, $C_{2s}^i = c_{2s}^i$, and

$$\begin{aligned} X_2^{i,\Delta} &= u^{-1} \left(\sum_{i=L,H} q_i \left[p \left\{ \Sigma^i u(x_{2h}^{i1}) + (1 - \Sigma^i) u(x_{2h}^{i0}) \right\} + (1 - p) u(x_{2l}^i) \right] \right) \\ &< p\theta + \omega - \sum_i \left\{ C_1^i + p \left[\Sigma^i (1 - \lambda^i) \theta + (1 - \Sigma^i) C_{2h}^i + (1 - p) C_{2l}^i \right] \right\} \end{aligned}$$

Easily the contracts are incentive compatible for the same strategies as the contracts with bilateral clearing. Moreover all constraints are easily satisfied by concavity of $u(\cdot)$. Then it has to be

$$V^{CCP,e=0} \geq u(X_2^{i,\Delta}) = V^{bil,e=0}$$

meaning that the contract with CCP clearing and no screening dominates the contract with bilateral clearing and no screening. ■

7.18 Proof of Lemma 18

Proof. Suppose not: suppose that the contract with bilateral clearing and screening dominates both the contract with central clearing and screening and the contract with CCP clearing and pooling over λ^L .

Let $(x_{2h}^i, x_{2l}^i, c_1^i, c_{2h}^i, c_{2l}^i)$ be the optimal contracts with bilateral clearing, when the lender upon screening learns that her counterparty is of type i . Similarly, let $(w^{i*}, C_{2h}^{i*}, C_{2l}^{i*}, C_1^{i*})$ be the optimal contract with CCP clearing and screening.

Since the contract with bilateral clearing dominates the contract with CCP clearing and screening, we have

$$qV_H + (1 - q)V_L > V^{FI} \tag{77}$$

Moreover, since the contract with bilateral clearing and screening dominates the contract with CCP clearing and pooling over λ^L ,

$$qV_H + (1 - q)V_L \geq V^{CCP,\lambda^L}$$

Define then the contract $(X_2, C_1^i, C_{2h}^i, C_{2l}^i)$ with $C_1^i = c_1^L$, $C_{2,s}^i = c_{2,s}^L$, and $X_2 = u^{-1}(V_L + \gamma)$.

Therefore

$$V^{CCP, \lambda^L} \geq V_L + \gamma$$

Put together the two expressions:

$$\begin{aligned} qV_H + (1-q)V_L &\geq V^{CCP, \lambda^L} \geq V_L + \gamma \\ \Rightarrow V_H &\geq V_L + \frac{\gamma}{q} \end{aligned}$$

where

$$\begin{aligned} V_H &= pu(x_{2h}^H) + (1-p)u(x_{2l}^H) - \gamma \\ V_L &= pu(x_{2h}^L) + (1-p)u(x_{2l}^L) - \gamma \end{aligned}$$

Therefore

$$pu(x_{2h}^H) + (1-p)u(x_{2l}^H) \geq pu(x_{2h}^L) + (1-p)u(x_{2l}^L) + \frac{\gamma}{q}$$

Define now w^H and w^L as the lenders' utilities from bilateral clearing, gross of the screening cost γ :

$$\begin{aligned} w^H &= pu(x_{2h}^H) + (1-p)u(x_{2l}^H) = V_H + \gamma \\ w^L &= pu(x_{2h}^L) + (1-p)u(x_{2l}^L) = V_L + \gamma \end{aligned}$$

Concavity of $u(\cdot)$ gives us that

$$u^{-1}(w^H) < px_{2h}^H + (1-p)x_{2l}^H = \omega - c_1^H + p\theta - pc_{2h}^H - (1-p)c_{2l}^H$$

Similarly,

$$u^{-1}(w^L) < px_{2h}^L + (1-p)x_{2l}^L = \omega - c_1^L + p\theta - pc_{2h}^L - (1-p)c_{2l}^L$$

Consider then the contract with CCP clearing $(w^i, C_{2h}^i, C_{2l}^i, C_1^i)$, where w^H and w^L are

defined above, $C_1^i = c_1^i$, $C_{2h}^i = c_{2h}^i$, $C_{2l}^i = c_{2l}^i$. Easily if $[q + (1 - q)(1 - p)]w^H < w^L$, all constraints in the CCP problem (\hat{P}^{FI}) are automatically satisfied. Then, by definition of optimality, it must be that

$$V^{FI} = qw^{H^*} + (1 - q)w^{L^*} \geq qw^H + (1 - q)w^L = qV_H + (1 - q)V_L$$

that contradicts equation (77). Then it must be that $[q + (1 - q)(1 - p)]w^H > w^L$, so the relevant incentive constraint in the full information problem of the CCP is $-\gamma + qw^H + (1 - q)w^L \geq [q + (1 - q)(1 - p)]w^H$. In this case, if the incentive constraint for screening is satisfied then the CCP solution always dominates the bilateral one because for any pair (w^H, w^L) such that $[q + (1 - q)(1 - p)]w^H > w^L$, the CCP can always find an alternative pair (w^H, w^L) that violates $[q + (1 - q)(1 - p)]w^H > w^L$, satisfies the incentive constraint $-\gamma + qw^H + (1 - q)w^L \geq w^L$, and yields strictly higher utility to lenders.

Then, it must be that the incentive compatibility constraint for screening is not satisfied by such a contract: it has to be $[q + (1 - q)(1 - p)]w^H > w^L$ and $-\gamma + qw^H + (1 - q)w^L < [q + (1 - q)(1 - p)]w^H$. Consider then the solution to problem $(\hat{P}b^{FI})$: we know from Lemma 4 that $(C_1^{i^*}, C_{2h}^{i^*}, C_{2l}^{i^*})$ solve problem $(\hat{P}b^{FI})$. Moreover, by definition of the maximization problem, it has to be that

$$\begin{aligned} \Omega^* &= p\theta + \omega - q[C_1^{H^*} + pC_{2h}^{H^*} + (1 - p)C_{2l}^{H^*}] - (1 - q)[C_1^{L^*} + pC_{2h}^{L^*} + (1 - p)C_{2l}^{L^*}] \\ &\geq p\theta + \omega - q[c_1^H + pc_{2h}^H + (1 - p)c_{2l}^H] - (1 - q)[c_1^L + pc_{2h}^L + (1 - p)c_{2l}^L] \\ &= q[p(\theta - c_{2h}^H + \omega - c_1^H) + (1 - p)(\omega - c_{2l}^H)] + (1 - q)[p(\theta - c_{2h}^L + \omega - c_1^L) + (1 - p)(\omega - c_{2l}^L)] \\ &= q[px_{2h}^H + (1 - p)x_{2l}^H] + (1 - q)[px_{2h}^L + (1 - p)x_{2l}^L] \\ &> qu^{-1}(w^H) + (1 - q)u^{-1}(w^L) \end{aligned}$$

Define then

$$\delta = \Omega - qu^{-1}(w^H) + (1 - q)u^{-1}(w^L)$$

and define $w^{H'}$ such that

$$u^{-1}(w^{H'}) = u^{-1}(w^H) + \frac{\delta}{q} \quad (78)$$

Since $u^{-1}(\cdot)$ is increasing, $w^{H'} \geq w^H$. Define now the operator

$$T(y) = u \left(\frac{qu^{-1}(w^{H'}) + (1-q)u^{-1}(w^L) - qu^{-1}\left(\frac{y}{q+(1-p)(1-q)}\right)}{1-q} \right) - y$$

Notice that $T(y)$ is monotone decreasing in y , that for $y = \bar{y} \equiv [q+(1-p)(1-q)]u \left(\frac{qu^{-1}(w^{H'})+(1-q)u^{-1}(w^L)}{q} \right) > 0$, it is

$$T(\bar{y}) = u(0) - \bar{y} < 0$$

Furthermore, the two conditions $w^{H'} \geq w^L + \frac{\gamma}{q}$ and $w^{H'} \geq \frac{w^L}{1-p} - \frac{\gamma}{(1-q)(1-p)}$, imply that $w^{H'} \geq \frac{w^L}{q+(1-p)(1-q)}$. where the second inequality follows from $w^{H'} \geq w^H > \frac{w^L}{1-p} - \frac{\gamma}{(1-q)(1-p)}$, which results from the assumption that the incentive constraint is violated, $-\gamma + qw^H + (1-q)w^L < [q+(1-q)(1-p)]w^H$, and from the definition of $w^{H'}$ that implies $w^{H'} \geq w^H$. Then for $y = w^L$ it is true that

$$\begin{aligned} T(w^L) &= u \left(\frac{qu^{-1}(w^{H'}) + (1-q)u^{-1}(w^L) - qu^{-1}\left(\frac{w^L}{q+(1-p)(1-q)}\right)}{1-q} \right) - w^L \\ &\geq u(u^{-1}(w^L)) - w^L = 0 \end{aligned}$$

By the intermediate value theorem, there must be a $w^{L''} \geq w^L$ such that $T(w^{L''}) = 0$. Define then $w^{L''} \in [w^L, \bar{y})$ to be the value that satisfies $T(w^{L''}) = 0$, and then define $w^{H''}$ as the solution to

$$w^{H''} = \frac{w^{L''}}{q+(1-p)(1-q)}$$

Notice that $w^{H''} \leq w^{H'}$, since $w^{L''} \geq w^L$.

Consider then the contract $(w^{H''}, w^{L''}, C_1^{i*}, C_{2h}^{i*}, C_{2l}^{i*})$, where $w^{H''}$ and $w^{L''}$ are defined above, and $C_1^{i*}, C_{2h}^{i*}, C_{2l}^{i*}$ solve problem $(\hat{P}b^{FI})$. Notice that this contract is feasible and satisfy the limited commitment constraint in problem (\hat{P}^{FI}) : participation, limited commitment

and feasibility constraints are easily satisfied by the definition of C_1^{i*} , C_{2h}^{i*} , C_{2l}^{i*} . Moreover, by construction $[1 + (1 - q)(1 - p)]w^{H''} = w^{L''}$. All is left to show is that this contract is incentive compatible. By construction, via the operator T

$$qu^{-1}(w^{H''}) + (1 - q)u^{-1}(w^{L''}) = qu^{-1}(w^{H'}) + (1 - q)u^{-1}(w^L) = \Omega^* \geq \hat{\Omega}$$

Replacing $w^{H''}$, $w^{L''}$ and $\hat{\Omega}$ with their definitions we can rewrite

$$qu^{-1}\left(\frac{w^{L''}}{q + (1 - p)(1 - q)}\right) + (1 - q)u^{-1}(w^{L''}) \geq qu^{-1}\left(\frac{\hat{w}^L}{q + (1 - p)(1 - q)}\right) + (1 - q)u^{-1}(\hat{w}^L)$$

Notice that this can hold if and only if $w^{L''} \geq \hat{w}^L$ and therefore $w^{H''} \geq \hat{w}^H$. Moreover, recall that $\hat{w}^H = \hat{w}^L + \frac{\gamma}{q}$. Therefore, for $w^{L''} \geq \hat{w}^L$ and $w^{H''} \geq \hat{w}^H$, the following hold:

$$\begin{aligned} w^{H''} &= \hat{w}^H + \frac{1}{q + (1 - q)(1 - p)}(w^{L''} - \hat{w}^L) \\ &= \hat{w}^L + \frac{\gamma}{q} + \frac{1}{q + (1 - q)(1 - p)}(w^{L''} - \hat{w}^L) \\ &= \hat{w}^L + \frac{\gamma}{q} + \frac{1}{q + (1 - q)(1 - p)}(w^{L''} - \hat{w}^L) + w^{L''} - w^{L''} \\ &= w^{L''} + \frac{\gamma}{q} + (w^{L''} - \hat{w}^L) \left[\frac{1}{q + (1 - q)(1 - p)} - 1 \right] \geq w^{L''} + \frac{\gamma}{q} \end{aligned}$$

that proves that the contract $(w^{H''}, w^{L''}, C_1^{i*}, C_{2h}^{i*}, C_{2l}^{i*})$ satisfies as well the incentive compatibility constraint. Then, by the definition of optimality, it must be

$$\begin{aligned} V^{FI} &\geq qw^{H''} + (1 - q)w^{L''} \\ &= qw^{H''} + (1 - q)u\left(\frac{qu^{-1}(w^{H'}) + (1 - q)u^{-1}(w^L) - qu^{-1}(w^{H''})}{1 - q}\right) \\ &= qw^{H''} + (1 - q)u\left(\frac{qu^{-1}(w^H) + \delta + (1 - q)u^{-1}(w^L) - qu^{-1}(w^{H''})}{1 - q}\right) \\ &= qw^{H''} + (1 - q)u\left(\frac{\Omega - qu^{-1}(w^{H''})}{1 - q}\right) \\ &= q\left(w^{H'} - \int_{w^{H''}}^{w^{H'}} 1 ds\right) + (1 - q)\left(w^L + \int_{w^{H''}}^{w^{H'}} \left[u' \left(\frac{\Omega - qu^{-1}(s)}{1 - q}\right) \frac{q}{1 - q} \frac{1}{u'(s)}\right] ds\right) \end{aligned}$$

$$\begin{aligned}
&= qw^{H'} + (1-q)w^L + q \int_{w^{H''}}^{w^{H'}} \left[\frac{u' \left(\frac{\Omega - qu^{-1}(s)}{1-q} \right)}{u'(s)} - 1 \right] ds \\
&\geq qw^{H'} + (1-q)w^L \geq qw^H + (1-q)w^L = qV_H + (1-q)V_L
\end{aligned}$$

where the first inequality in the last line follows from the fact that $\frac{\Omega - qu^{-1}(s)}{1-q} < s$ for all $s \in (w^{H''}, w^{H'}]$, and the inequality in the last line follows from the fact that $w^{H'} \geq w^H$, given the definition in (78). But this contradicts (77). ■

7.19 Proof of Lemma 19

Proof. Suppose first that $\lambda^L \geq \bar{\lambda}^L = \lambda^*$. As $\lambda^H > \lambda^L$, $\lambda^H > \lambda^*$ as well. Moreover, $\lambda^* \geq 1 - \frac{\alpha\omega}{p\theta}$ gives us $\omega \geq \frac{(1-\lambda^*)p\theta}{\alpha}$. Then from Lemma 3, we have $c_{2,h} = \frac{\omega - c_1^*}{p} > (1 - \lambda^L)\theta$, and

$$V_H = V_L = pu \left(\theta - (\alpha - p) \frac{\omega - c_1^*}{p} \right) + (1-p)u(\omega - c_1^*) - \gamma$$

Moreover, from Lemma 12, we have $V^{CCP, \lambda^L} = u \left(\frac{(1-\lambda^L)p\theta}{\alpha} + \lambda^L p\theta \right)$. Combining the two expressions and using concavity of $u(\cdot)$, we have

$$\begin{aligned}
V^{bil, e=0} &= pu \left(\theta - (\alpha - p) \frac{\omega - c_1^*}{p} \right) + (1-p)u(\omega - c_1^*) - \gamma \\
&< u \left(p\theta - (\alpha - 1)(\omega - c_1^*) \right) < u \left(p\theta - (\alpha - 1) \frac{(1-\lambda^L)p\theta}{\alpha} \right) \\
&= u \left(\frac{(1-\lambda^L)p\theta}{\alpha} + \lambda^L p\theta \right) = V^{CCP, \lambda^L}
\end{aligned}$$

which proves that if $\lambda^L \geq \bar{\lambda}^L = \lambda^*$, then the contract with central clearing and pooling over λ^L dominates the contract with information acquisition and bilateral clearing.

Suppose now that $\lambda^L \geq \bar{\lambda}^L = 1 - \frac{\alpha\omega}{p\theta} > \lambda^*$. Then, as $\lambda^H > \lambda^L$, we have $\lambda^H > \lambda^*$ as well. Moreover, since $1 - \frac{\alpha\omega}{p\theta} > \lambda^*$, we have $\omega < \frac{(1-\lambda^*)p\theta}{\alpha}$. Then from Lemma 3, we have $\frac{\alpha\omega}{p} = c_{2h} > (1 - \lambda^L)\theta$, so $\omega \geq \frac{(1-\lambda^L)p\theta}{\alpha}$, and

$$V_H = V_L = pu \left(\theta - (\alpha - p) \frac{\omega}{p} \right) + (1-p)u(\omega) - \gamma$$

Moreover, from Lemma 12, we have $V^{CCP,\lambda^L} = u\left(\frac{(1-\lambda^L)p\theta}{\alpha} + \lambda^L p\theta\right)$. Combining the two expressions and using concavity of $u(\cdot)$, we have

$$\begin{aligned} V^{bil,e=0} &= pu\left(\theta - (\alpha - p)\frac{\omega}{p}\right) + (1-p)u(\omega) - \gamma \\ &< u(p\theta - (\alpha - 1)\omega) < u\left(p\theta - (\alpha - 1)\frac{(1-\lambda^L)p\theta}{\alpha}\right) \\ &= u\left(\frac{(1-\lambda^L)p\theta}{\alpha} + \lambda^L p\theta\right) = V^{CCP,\lambda^L} \end{aligned}$$

that proves that if $\lambda^L \geq \bar{\lambda}^L = 1 - \frac{\alpha\omega}{p\theta} > \lambda^*$, then central clearing and pooling over λ^L dominates information acquisition and bilateral clearing. So we have proven the first half of the Lemma: if $\lambda^L \geq \bar{\lambda}^L \equiv \max\left\{\lambda^*, 1 - \frac{\alpha\omega}{p\theta}\right\}$, the contract with central clearing and pooling over λ^L dominates the contract with information acquisition and bilateral clearing.

Suppose now that $\lambda^H < \underline{\lambda}^H = 1 - \frac{\alpha\omega}{p\theta}$. Then as $\lambda^L < \lambda^H$, we have $1 - \frac{\alpha\omega}{p\theta} \geq \lambda^H > \lambda^L$. Then from Lemma 3 we have

$$\begin{aligned} V_H &= p(\omega + \lambda^H\theta) + (1-p)u(\omega) - \gamma \\ V_L &= p(\omega + \lambda^L\theta) + (1-p)u(\omega) - \gamma \end{aligned}$$

From Lemma 15, we have that $V^{CCP,\lambda^H} = u(\omega + p\theta[q\lambda^H + (1-q)\lambda^L])$. Combining the two expressions and using concavity of $u(\cdot)$, we have

$$\begin{aligned} V^{bil,e=0} &= qV_H + (1-q)V_L - \gamma \\ &= (1-p)u(\omega) + p[qu(\omega + \lambda^H\theta) + (1-q)u(\omega + \lambda^L\theta)] - \gamma \\ &< u(\omega + p\theta[q\lambda^H + (1-q)\lambda^L]) = V^{CCP,\lambda^H} \end{aligned}$$

that proves that if $\lambda^H < \underline{\lambda}^H = 1 - \frac{\alpha\omega}{p\theta}$, then central clearing and pooling over λ^H dominates information acquisition and bilateral clearing.

Suppose finally that $\lambda^H > \underline{\lambda}^H > \lambda^*$. Then from Lemma 3 we have

$$\begin{aligned} V_H &= \left[pu \left(\omega + \theta - \frac{\alpha}{p} \omega \right) + (1-p) u(\omega) \right] - \gamma \\ V_L &= [pu(\omega + \theta \lambda^L) + (1-p)u(\omega)] - \gamma \end{aligned}$$

If $q \geq \frac{1}{\alpha}$, from Lemma 15 we have $V^{CCP, \lambda^H} = u \left(\frac{(1-\lambda^H)p\theta}{\alpha} + p\theta[q\lambda^H + (1-q)\lambda^L] \right)$. Combining the two expressions, using concavity of $u(\cdot)$, $\lambda^H > \underline{\lambda}^H$, and the fact that $q \geq \frac{1}{\alpha}$, we have

$$\begin{aligned} V^{bil, e=1} &= qV_H + (1-q)V_L < u(\omega + qp\theta - q\alpha\omega + (1-q)p\theta\lambda^L) - \gamma \\ &= u \left(\frac{(1-\lambda^H)p\theta}{\alpha} + p\theta[q\lambda^H + (1-q)\lambda^L] + \left[\omega - \frac{(1-\lambda^H)p\theta}{\alpha} \right] (1-q\alpha) \right) - \gamma \\ &< u \left(\frac{(1-\lambda^H)p\theta}{\alpha} + p\theta[q\lambda^H + (1-q)\lambda^L] \right) - \gamma \\ &= V^{CCP, \lambda^H} - \gamma < V^{CCP, \lambda^H} \end{aligned}$$

If instead $q < \frac{1}{\alpha}$, from Lemma 15 we have $V^{CCP, \lambda^H} = u(\omega(1-\alpha q) + p\theta - (1-q)(1-\lambda^L)p\theta)$. Combining this with the payoffs from bilateral clearing, using concavity of $u(\cdot)$, we get

$$\begin{aligned} V^{bil, e=1} &= qV_H + (1-q)V_L < u(\omega + qp\theta - q\alpha\omega + (1-q)p\theta\lambda^L) - \gamma \\ &= V^{CCP, \lambda^H} - \gamma < V^{CCP, \lambda^H} \end{aligned}$$

that completes the proof. ■

7.20 Proof of Proposition 21

Proof. If $\gamma > \hat{\gamma}^{(\omega)}$, with $\hat{\gamma}^{(\omega)}$ defined consistently with (43), then the full information contract with CCP clearing is not implementable.

CASE 1: CCP contract pools over λ^L .

If $q \leq \frac{1}{\alpha}$ and $\omega \geq \frac{p\theta}{\alpha}(1-\lambda^L)$ then the best contract with CCP clearing is the pooling contract over λ^L . Also, lemma 19 implies that only $\lambda^L < \bar{\lambda}^L$ and $\lambda^H > \underline{\lambda}^H$ may be consistent

with bilateral clearing and information acquisition as an equilibrium outcome. Since $\omega \geq \frac{p\theta}{\alpha} (1 - \lambda^L) > \frac{p\theta}{\alpha} (1 - \lambda^H)$, then $\bar{\lambda}^L = \lambda^*$, and $\lambda^H < \underline{\lambda}^H$ is satisfied.

Thus $\hat{\gamma}^{(\omega)}$ in this case is:

$$\phi(\hat{\gamma}^{(\omega)}) = q \left[\frac{(1 - \lambda^H)p\theta}{\alpha} + \lambda^H p\theta \right] + (1 - q) \left[\frac{(1 - \lambda^L)p\theta}{\alpha} + \lambda^L p\theta \right] \quad (79)$$

Lenders payoff with CCP clearing is $V^{CCP, \lambda^L} = u \left(\frac{p\theta}{\alpha} (1 - \lambda^L) + p\theta \lambda^L \right)$. Lenders' payoff with bilateral clearing, since $\lambda^L < \lambda^*$, depends on whether (i) $\lambda^L < \lambda^* < \lambda^H$ or (ii) $\lambda^L < \lambda^H < \lambda^*$.

(i) $\lambda^L < \lambda^* < \lambda^H$.

Claim 22 *If $\omega \geq \frac{(1 - \lambda^L)p\theta}{\alpha}$, $\lambda^H > \lambda^* > \lambda^L$, $\alpha q \leq 1$, and $\gamma \geq \hat{\gamma}^{(\omega)}$, the optimal contract is such that:*

(a) *bilateral clearing and information acquisition if $\gamma \leq \bar{\gamma}^a$.*

(b) *CCP clearing and pooling over λ^L if $\gamma > \bar{\gamma}^a$.*

Proof. The expected payoff from bilateral clearing, using $\omega - c_1^* = \frac{p\theta}{\alpha} (1 - \lambda^*)$, to lenders is:

$$\begin{aligned} & -\gamma + q \left[pu \left(\omega - c_1^* + \theta - \frac{\alpha}{p} (\omega - c_1^*) \right) + (1 - p) u (\omega - c_1^*) \right] + \\ & (1 - q) \left[pu \left(\frac{p\theta}{\alpha} (1 - \lambda^L) + \theta \lambda^L \right) + (1 - p) u \left(\frac{p\theta}{\alpha} (1 - \lambda^L) \right) \right] \end{aligned} \quad (80)$$

Hence bilateral clearing is preferred to CCP clearing if $\gamma < \bar{\gamma}^a$, where

$$\begin{aligned} \bar{\gamma}^a = & q \left[pu \left(\frac{p\theta}{\alpha} (1 - \lambda^*) + \lambda^* \theta \right) + (1 - p) u \left(\frac{p\theta}{\alpha} (1 - \lambda^*) \right) \right] \\ & + (1 - q) \left[pu \left(\frac{p\theta}{\alpha} (1 - \lambda^L) + \theta \lambda^L \right) + (1 - p) u \left(\frac{p\theta}{\alpha} (1 - \lambda^L) \right) \right] \\ & - u \left(\frac{p\theta}{\alpha} (1 - \lambda^L) + p\theta \lambda^L \right) \end{aligned} \quad (81)$$

■

(ii) $\lambda^L < \lambda^H < \lambda^*$.

Claim 23 *If $\omega \geq \frac{(1-\lambda^L)p\theta}{\alpha}$, $\lambda^* > \lambda^H > \lambda^L$, $\alpha q \leq 1$, and $\gamma \geq \hat{\gamma}^{(\omega)}$, the optimal contract is such that:*

(a) *bilateral clearing and information acquisition if $\gamma \leq \bar{\gamma}^b$.*

(b) *CCP clearing and pooling over λ^L if $\gamma > \bar{\gamma}^b$.*

Proof.

The expected payoff from bilateral clearing to lenders is:

$$q \left[pu \left(\frac{(1-\lambda^H)p\theta}{\alpha} + \lambda^H\theta \right) + (1-p)u \left(\frac{(1-\lambda^H)p\theta}{\alpha} \right) \right] + \\ (1-q) \left[pu \left(\frac{p\theta}{\alpha} (1-\lambda^L) + \theta\lambda^L \right) + (1-p)u \left(\frac{p\theta}{\alpha} (1-\lambda^L) \right) \right] - \gamma$$

Bilateral clearing is preferred if $\gamma < \bar{\gamma}^b$ where

$$\bar{\gamma}^b = q \left[pu \left(\frac{(1-\lambda^H)p\theta}{\alpha} + \lambda^H\theta \right) + (1-p)u \left(\frac{(1-\lambda^H)p\theta}{\alpha} \right) \right] + \\ (1-q) \left[pu \left(\frac{p\theta}{\alpha} (1-\lambda^L) + \theta\lambda^L \right) + (1-p)u \left(\frac{p\theta}{\alpha} (1-\lambda^L) \right) \right] \\ - u \left(\frac{p\theta}{\alpha} (1-\lambda^L) + p\theta\lambda^L \right)$$

■

CASE 2: CCP contract pools over λ^H .

If either $\omega < \frac{p\theta}{\alpha} (1-\lambda^L)$ or $\omega > \frac{p\theta}{\alpha} (1-\lambda^L)$ and $q > \frac{1}{\alpha}$ then the best contract with CCP clearing pools over λ^H . When $\omega < \frac{p\theta}{\alpha} (1-\lambda^L)$, we need to distinguish the two sub-cases: first $\omega < \frac{p\theta}{\alpha} (1-\lambda^H)$, second $\frac{p\theta}{\alpha} (1-\lambda^H) < \omega < \frac{p\theta}{\alpha} (1-\lambda^L)$.

1. $\omega < \frac{p\theta}{\alpha} (1-\lambda^H)$.

Lemma 19 shows that in this case central clearing is always preferred to bilateral clearing.

2. $\frac{p\theta}{\alpha}(1 - \lambda^H) < \omega \leq \frac{(1 - \lambda^L)p\theta}{\alpha}$ and $q \geq \frac{1}{\alpha}$.

In this case, consistently with lemma 19, $\lambda^L < \bar{\lambda}^L$ and $\lambda^H > \underline{\lambda}^H$

Also, $\hat{\gamma}^{(\omega)}$ is defined as follows:

$$\phi(\hat{\gamma}^{(\omega)}) = q \left[\frac{(1 - \lambda^H)p\theta}{\alpha} + \lambda^H p\theta \right] + (1 - q) [\omega + \lambda^L p\theta] \quad (82)$$

Lenders' payoff with central clearing is $V^{CCP, \lambda^H} = u \left(\frac{(1 - \lambda^H)p\theta}{\alpha} + p\theta[q\lambda^H + (1 - q)\lambda^L] \right)$.

Lenders' payoff with bilateral clearing, since both $\lambda^L < \lambda^*$ and $\lambda^* < \lambda^L < 1 - \frac{\alpha\omega^*}{p\theta}$ are feasible, depends on whether (i) $\lambda^H \geq \lambda^*$ and $\omega > \omega^* = \frac{(1 - \lambda^*)p\theta}{\alpha}$, (ii) $\lambda^H \geq \lambda^*$ and $\omega \leq \omega^*$, or (iii) $\lambda^H < \lambda^*$.

(i) $\lambda^H \geq \lambda^*$, $\omega > \omega^*$.

Claim 24 If $\frac{p\theta}{\alpha}(1 - \lambda^L) \geq \omega > \frac{p\theta}{\alpha}(1 - \lambda^H)$, $\lambda^H \geq \lambda^*$, $\omega \geq \omega^*$, $q \geq \frac{1}{\alpha}$, and

$\gamma \geq \hat{\gamma}^{(\omega)}$, the optimal contract involves

i. bilateral clearing and information acquisition if $\gamma \leq \bar{\gamma}^c$.

ii. CCP clearing and pooling over λ^H if $\gamma > \bar{\gamma}^c$.

Proof.

The expected payoff from bilateral clearing to lenders is:

$$q \left[pu \left(\omega - c_1^* + \theta - \frac{\alpha}{p} (\omega - c_1^*) \right) + (1 - p) u (\omega - c_1^*) \right] + (1 - q) [pu (\omega + \theta\lambda^L) + (1 - p) u(\omega)] - \gamma$$

Bilateral clearing is preferred if $\gamma < \bar{\gamma}^b$ where

$$\bar{\gamma}^c = q \left[pu \left(\frac{(1 - \lambda^*)p\theta}{\alpha} + \lambda^*\theta \right) + (1 - p) u \left(\frac{(1 - \lambda^*)p\theta}{\alpha} \right) \right] + (1 - q) [pu (\omega + \theta\lambda^L) + (1 - p) u(\omega)] - u \left(\frac{(1 - \lambda^H)p\theta}{\alpha} + p\theta[q\lambda^H + (1 - q)\lambda^L] \right)$$

■

(ii) $\lambda^H \geq \lambda^*$, $\omega \leq \omega^*$. This is true by Lemma 19.

(iii) $\lambda^H < \lambda^*$.

Claim 25 *If $\frac{p\theta}{\alpha}(1 - \lambda^H) \geq \omega > \frac{p\theta}{\alpha}(1 - \lambda^H)$, $\lambda^H < \lambda^*$, $q \geq \frac{1}{\alpha}$, and $\gamma \geq \hat{\gamma}^b$, the optimal contract involves*

i. bilateral clearing and information acquisition if $\gamma \leq \bar{\gamma}^d$.

ii. CCP clearing and pooling over λ^H if $\gamma > \bar{\gamma}^d$.

Proof.

The expected payoff from bilateral clearing to lenders is:

$$q \left[pu \left(\frac{(1 - \lambda^H)p\theta}{\alpha} + \lambda^H\theta \right) + (1 - p) u \left(\frac{(1 - \lambda^H)p\theta}{\alpha} \right) \right] + (1 - q) [pu(\omega + \theta\lambda^L) + (1 - p)u(\omega)] - \gamma$$

Bilateral clearing is preferred if $\gamma < \bar{\gamma}^d$ where

$$\bar{\gamma}^d = q \left[pu \left(\frac{(1 - \lambda^H)p\theta}{\alpha} + \lambda^H\theta \right) + (1 - p) u \left(\frac{(1 - \lambda^H)p\theta}{\alpha} \right) \right] + (1 - q) [pu(\omega + \theta\lambda^L) + (1 - p)u(\omega)] - u \left(\frac{(1 - \lambda^H)p\theta}{\alpha} + p\theta[q\lambda^H + (1 - q)\lambda^L] \right)$$

■

3. $\frac{p\theta}{\alpha}(1 - \lambda^H) < \omega \leq \frac{(1 - \lambda^L)p\theta}{\alpha}$ and $q < \frac{1}{\alpha}$.

Lenders' payoff with central clearing is then $V^{CCP, \lambda^H} = u(\omega(1 - \alpha q) + p\theta - (1 - q)(1 - \lambda^L)p\theta)$. Lenders' payoff with bilateral clearing, as in the previous case, depends on whether (i) $\lambda^H \geq \lambda^*$ and $\omega > \omega^* = \frac{(1 - \lambda^*)p\theta}{\alpha}$, (ii) $\lambda^H \geq \lambda^*$ and $\omega \leq \omega^*$, or (iii) $\lambda^H < \lambda^*$.

(i) $\lambda^H \geq \lambda^*$, $\omega > \omega^*$.

Claim 26 *If $\frac{p\theta}{\alpha}(1 - \lambda^L) \geq \omega > \frac{p\theta}{\alpha}(1 - \lambda^H)$, $\lambda^H \geq \lambda^*$, $\omega \geq \omega^*$, $q < \frac{1}{\alpha}$, $q \geq \frac{1}{\alpha}$, and $\gamma \geq \hat{\gamma}^{(\omega)}$, the optimal contract involves*

i. bilateral clearing and information acquisition if $\gamma \leq \bar{\gamma}^e$.

ii. CCP clearing and pooling over λ^H If $\gamma > \bar{\gamma}^e$.

Proof.

The expected payoff from bilateral clearing to lenders is:

$$q \left[pu \left(\omega - c_1^* + \theta - \frac{\alpha}{p} (\omega - c_1^*) \right) + (1-p) u(\omega - c_1^*) \right] + (1-q) [pu(\omega + \theta\lambda^L) + (1-p)u(\omega)] - \gamma$$

Bilateral clearing is preferred if $\gamma < \bar{\gamma}^e$ where

$$\bar{\gamma}^e = q \left[pu \left(\frac{(1-\lambda^*)p\theta}{\alpha} + \lambda^*\theta \right) + (1-p) u \left(\frac{(1-\lambda^*)p\theta}{\alpha} \right) \right] + (1-q) [pu(\omega + \theta\lambda^L) + (1-p)u(\omega)] - u(\omega(1-\alpha q) + p\theta - (1-q)(1-\lambda^L)p\theta)$$

■

(ii) $\lambda^H \geq \lambda^*$, $\omega \leq \omega^*$. This case is ruled out by Lemma 19.

(iii) $\lambda^H < \lambda^*$.

Claim 27 If $\frac{p\theta}{\alpha}(1-\lambda^H) \geq \omega > \frac{p\theta}{\alpha}(1-\lambda^H)$, $\lambda^H < \lambda^*$, $q < \frac{1}{\alpha}$, and $\gamma \geq \hat{\gamma}^{(\omega)}$, the optimal contract involves

i. bilateral clearing and information acquisition if $\gamma \leq \bar{\gamma}^g$.

ii. CCP clearing and pooling over λ^H if $\gamma > \bar{\gamma}^g$.

Proof. The expected payoff from bilateral clearing to lenders is:

$$q \left[pu \left(\frac{(1-\lambda^H)p\theta}{\alpha} + \lambda^H\theta \right) + (1-p) u \left(\frac{(1-\lambda^H)p\theta}{\alpha} \right) \right] + (1-q) [pu(\omega + \theta\lambda^L) + (1-p)u(\omega)] - \gamma$$

Bilateral clearing is preferred if $\gamma < \bar{\gamma}^g$ where

$$\begin{aligned} \bar{\gamma}^g = & q \left[pu \left(\frac{(1-\lambda^H)p\theta}{\alpha} + \lambda^H\theta \right) + (1-p)u \left(\frac{(1-\lambda^H)p\theta}{\alpha} \right) \right] + \\ & (1-q) \left[pu(\omega + \theta\lambda^L) + (1-p)u(\omega) \right] - u(\omega(1-\alpha q) + p\theta - (1-q)(1-\lambda^L)p\theta) \end{aligned}$$

■

4. $\omega > \frac{p\theta}{\alpha}(1-\lambda^L)$ and $q \geq \frac{1}{\alpha}$.

Lenders' payoff with central clearing is then $V^{CCP, \lambda^H} = u \left(\frac{(1-\lambda^H)p\theta}{\alpha} + p\theta[q\lambda^H + (1-q)\lambda^L] \right)$.

Lenders' payoff with bilateral clearing depends on whether (i) $\lambda^H \geq \lambda^*$ and $\omega > \omega^*$, or (ii) $\lambda^H < \lambda^*$. In fact, in this case, $\lambda^L > 1 - \frac{\alpha\omega}{p\theta}$, thus lemma 19 implies that we can restrict to the case $\lambda^L < \lambda^*$.

Also, in this case $\phi(\hat{\gamma}^{(\omega)})$ is defined as follows:

$$\phi(\hat{\gamma}^{(\omega)}) = q[\omega + \lambda^H p\theta] + (1-q)[\omega + \lambda^L p\theta] \quad (83)$$

(i) $\lambda^H \geq \lambda^*$, $\omega > \omega^*$

Claim 28 *If $\omega \geq \frac{(1-\lambda^L)p\theta}{\alpha}$, $\lambda^H > \lambda^* > \lambda^L$, $\alpha q \geq 1$, and $\gamma \geq \hat{\gamma}^{(\omega)}$, the optimal contract involves*

i. bilateral clearing and information acquisition if $\gamma \leq \bar{\gamma}^h$.

ii. CCP clearing and pooling over λ^H if $\gamma > \bar{\gamma}^h$.

Proof. Lenders' expected payoff from bilateral clearing is to lenders is:

$$\begin{aligned} & q \left[pu \left(\omega - c_1^* + \theta - \frac{\alpha}{p}(\omega - c_1^*) \right) + (1-p)u(\omega - c_1^*) \right] + \\ & (1-q) \left[pu \left(\frac{p\theta}{\alpha}(1-\lambda^L) + \theta\lambda^L \right) + (1-p)u \left(\frac{p\theta}{\alpha}(1-\lambda^L) \right) \right] - \gamma \end{aligned}$$

Then using the fact that $\omega - c_1^* = \frac{(1-\lambda^*)p\theta}{\alpha}$, we can rewrite that bilateral clearing

is preferred if $\gamma \leq \bar{\gamma}^h$ defined as

$$\begin{aligned} \bar{\gamma}^h = & q \left[pu \left(\frac{(1-\lambda^*)p\theta}{\alpha} + \lambda^*\theta \right) + (1-p) u \left(\frac{(1-\lambda^*)p\theta}{\alpha} \right) \right] + \\ & (1-q) \left[pu \left(\frac{p\theta}{\alpha} (1-\lambda^L) + \theta\lambda^L \right) + (1-p) u \left(\frac{p\theta}{\alpha} (1-\lambda^L) \right) \right] - \\ & u \left(\frac{p\theta}{\alpha} (1-\lambda^H) + p\theta [q\lambda^H + (1-q)\lambda^L] \right) \end{aligned}$$

■

(ii) $\lambda^H < \lambda^*$.

Claim 29 If $\omega \geq \frac{(1-\lambda^L)p\theta}{\alpha}$, $\lambda^H < \lambda^*$, $\alpha q \geq 1$, and $\gamma \geq \hat{\gamma}^{(\omega)}$, the optimal contract involves

i. bilateral clearing and information acquisition if $\gamma \leq \bar{\gamma}^i$.

ii. CCP clearing and pooling over λ^H if $\gamma > \bar{\gamma}^i$.

Proof. Lenders' expected payoff from bilateral clearing is:

$$\begin{aligned} & q \left[pu \left(\frac{p\theta}{\alpha} (1-\lambda^H) + \lambda^H p\theta \right) + (1-p) u \left(\frac{p\theta}{\alpha} (1-\lambda^H) \right) \right] + \\ & (1-q) \left[pu \left(\frac{p\theta}{\alpha} (1-\lambda^L) + \theta\lambda^L \right) + (1-p) u \left(\frac{p\theta}{\alpha} (1-\lambda^L) \right) \right] - \gamma \end{aligned}$$

Then bilateral clearing is preferred if $\gamma \leq \bar{\gamma}^i$, with $\bar{\gamma}^i$ defined as follows:

$$\begin{aligned} \bar{\gamma}^i = & q \left[pu \left(\frac{p\theta}{\alpha} (1-\lambda^H) + \lambda^H p\theta \right) + (1-p) u \left(\frac{p\theta}{\alpha} (1-\lambda^H) \right) \right] + \\ & (1-q) \left[pu \left(\frac{p\theta}{\alpha} (1-\lambda^L) + \theta\lambda^L \right) + (1-p) u \left(\frac{p\theta}{\alpha} (1-\lambda^L) \right) \right] - \\ & u \left(\frac{p\theta}{\alpha} (1-\lambda^H) + p\theta [q\lambda^H + (1-q)\lambda^L] \right) \end{aligned}$$

■

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