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Abstract

This paper studies access regulation to international large-value payment systems when banking supervision is a national task. We focus on the choice between allowing net settlement or imposing real-time gross settlement. As a novel feature, the communication between the supervisors is endogenized. It is shown that the national supervisors' preferences regarding the settlement method are not perfectly aligned. As a result, systemic risk is excessive under public regulation. Still, leaving access regulation to the private banks can only be optimal if they have superior information about the risk of their foreign counterparty in the settlement system.

JEL Classifications: E58, G20, G28.

Keywords: Payment Systems, Regulation, Supervision, Systemic Risk

1. Introduction

The last decades have witnessed a substantial increase in the volume of transactions that are processed via large-value payment systems. In the US, for example, the combined payment value processed in CHIPS and Fedwire exceeded US $ 2.5 trillion per day in 1998. This trend is both a result of technological change and of increased financial activity. Because of the high volumes transferred and the large size of the individual payments (the average payment size in Fedwire was US $ 3.3 million), payment systems have grown to be one of the most likely channels through which financial crises could propagate.[1] Internationally, the growing integration of financial markets has led to a rapid increase in cross-border transactions, and raises fears that crises in different parts of the world could affect financial stability. The design of large-value payment systems, both on a domestic and on an international level, is thus of growing concern for system participants and financial regulators. For example, the G-10 countries established working committees in order to develop standards for interbank payment systems.[2]

Large-value payment systems can generally be classified into two types: gross systems, now usually operating in real time, and netting systems. In Real-Time-Gross-Settlement systems (RTGS), all transfers made between participating banks are cleared and settled immediately and irrevocably. As a result, a bank can be reasonably sure to receive a payment once it has been cleared, and credit and systemic risk in the settlement process are minimized. In net settlement systems, on the other hand, payments are cleared only at pre-specified settlement times, and only the net amounts of liabilities are actually transferred. Compared to gross settlement, netting thus significantly reduces the amount of reserves the banks need to maintain for settlement purposes. However, if a bank is unable to settle at the end of the day, its failure can have severe consequences for the other participants, as large amounts of expected payments will not be received. Clearly, there is a trade-off in efficiency between the two systems: if the failure of banks is relatively likely, a RTGS system is the better

[1] Statistics concerning the transfers in Fedwire and Chips can be found on the web page of Federal Reserve Bank of New York, http://www.ny.frb.org/pihome/fedpoint.

[2] Results of this work are the Angell Report (1989), the Lamfalussy Report (1990), and the Noël Report (1993).

choice since it limits the exposure to settlement and systemic risk. On the other hand, a netting system becomes more attractive the safer the banks that participate in the system, and the higher the opportunity cost of holding reserves. This basic trade-off between net and gross settlement systems has been analyzed by Freixas and Parigi (1998).

RTGS and net settlement systems frequently coexist. In the European Union, for example, the central banks of the EU countries have introduced TARGET, a cross-border RTGS system. Parallel to TARGET, privately or publicly organized net and hybrid settlement systems are operational (such as Euro-1, operated by the European Banking Association). In the US, the Federal Reserve Banks operate Fedwire, which is a RTGS system, while CHIPS is a privately run net settlement system.

In this paper, we study access regulation to coexisting net settlement and RTGS systems in an international environment. We look at a situation where banks of different nationalities settle their transfers through the payment system, and consider the problem of deciding whether the banks should be allowed to use the net system. Often, a lead overseer is in charge of regulating the organization of a settlement system and ensuring that certain standards are met. The supervision of the participating banks, on the other hand, is divided among the home-country authorities. We argue that the overseer should ideally make use of the supervisory information in regulating access to the net system. However, it is shown that the international division of supervisory power creates incentive problems in access regulation, because the national supervisors might have somewhat conflicting interests. Our original motivation for studying this problem were the European cross-border settlement systems. However, the issues that we study here also arise in domestic payments systems in which foreign banks participate, since the local branches of foreign banks are mostly supervised by the authority in the home country rather than in the host country.

We analyze an economy with two countries, where consumers make and receive cross-border transfers. In each country there is one commercial, profit-maximizing bank. The existence of banks is justified on two grounds: firstly, they are able to invest in profitable, long-run technologies, which short-lived consumers could not do. Secondly, banks are participating in an international payment system, enabling its customers to make transfers abroad. Banking supervision is the task of a local supervisor, who maximizes its own country's welfare. We assume that the local supervisor can observe the risk of the local but not the risk of the foreign bank. Concerning the private bank's information, we study two different scenarios. In the first, we assume that private banks have the same information as the supervisors. It seems plausible that a bank operating internationally is better informed about the risk of their foreign counterparties than the local supervisor, so as a second scenario we assume that private banks can perfectly observe each other's type.

In the economy a net and a gross settlement system are in operation. While banks have free access to the RTGS system, access to the net system is regulated. For simplicity, we abstract from explicitly modelling a supranational regulator. Instead, we assume that the local supervisors jointly decide upon the banks' access to the net settlement system.[3] Due to the division of supervisory responsibilities between countries, the supervisors have to rely on each other's information when regulating access to the system. We model the communication between the supervisors explicitly. It is shown that the supervisors have incentives to understate the risk of the local bank, because the foreign economy carries some of the costs of failure in a net settlement system. Therefore, the national supervisors allow too risky banks into the netting system. On the other hand, the private banks face limited liability, which induces them to choose net settlement too often as well. Systemic risk is therefore higher than desirable both when the public and the private sector decide upon access to the netting system. We find that if the private banks have the same information as the supervisors, the decision about the mode of settlement should be made by the supervisors. However, if the private banks possess superior information about the foreign banks' risks, it can be efficient to leave this decision to the private banks.

The literature on large-value payment systems is relatively small, but there are some papers that deal with issues related to ours. Kahn and Roberds (1998) model the trade-off between gross and net settlement, arguing that while a gross system requires

[3] In practice, different agencies are responsible for banking supervision and payment system oversight, which leads to information flows between supervisors, regulators, and often central banks, both within a country and cross-border. With our simplified setup with only two national agencies, we are nevertheless able to capture the need to coordinate information from different sources.

more reserve holdings, in a net system, participants might have incentives to default on their outstanding payments. The coexistence of net settlement and RTGS system is discussed in Rochet and Tirole (1996). Giannini and Monticelli (1995) point out that privately organized netting systems might undermine the European System of Central Banks' objectives of reducing systemic risk. Other authors (e.g., Giovannini (1992) and Schoenmaker (1995)) have studied problems concerning the division of banking supervisory powers within the European Union. To our knowledge, this is the first paper that provides a formal analysis of the regulation of international payment systems. As a novel feature, we take the division of supervisory powers among countries explicitly into account and endogenize the communication between the national supervisors. In the modelling of the communication, we draw on previous work by, in particular, Crawford and Sobel (1982) and Melumad and Shibano (1991).

The paper is organized as follows. In section 2, the model is described. Section 3 discusses the effects of gross and net settlement on the banks' portfolio choice and on systemic stability. In section 4, we analyze the access conditions to the net system imposed by public regulation. This is done first under the assumption that each supervisor can observe both banks' types, and then assuming local supervision. The private banks' access criteria are derived in section 5, and the efficiency of private and public solutions are compared. Some extensions of the model are discussed in section 6. Finally, section 7 concludes. All proofs are in the appendix.

2. The Model

The Economy We consider an OLG model with two countries and three periods. There are two generations of customers, who are born either at time 0 (customers "A") or at time 1 (customers "B"). They live for 2 periods each. Customers are endowed with one unit of money. During the first period of their lives, they wish to make payments to customers in the other country; e.g., for purchasing goods. The size of the payments that the customers want to make is taken to be fixed and equal to t. The customers wish to consume only in the second period of their lives and they are risk-neutral.

In each country, there is one bank. At time 0, the banks collect deposits from the local customers of generation A. These deposits can be invested both in central bank reserves, yielding zero interest, and in a risky country-specific technology with a positive expected return. After depositing, customers A can use their deposits to make payments to customers of the other bank. At time 1, customers A withdraw their money, and customers B deposit. The bank can thus use the newly deposited funds to pay parts of its obligation to customers A. All customers demand a non-negative expected return on their deposits.

At time 2, the risky technology yields a return of R, if successful, and 0 otherwise. The probability of failure of Country i's risky technology is denoted $\widetilde{q}_i$. In order to have asymmetric information about the riskiness of the local bank, we assume that $\widetilde{q}_i$ is a random variable. For simplicity, it is assumed that $\widetilde{q}_i$ is uniformly distributed between 0 and 1. The realization of $\widetilde{q}_i$ is denoted q_i (q_i is also called the bank's "type"). At time 1, the risky technology can be liquidated prematurely. Liquidation is costly, and the risky technology only pays L, $0 < L < 1$, if successful, and 0 if unsuccessful.

Payment Systems A customer in country i can make payments to a customer in country j by transferring funds from his account at bank i to the receiver's account at bank j. Transfers between banks are made via a payment system.

Payments can be settled either in a gross or in a net settlement system. The *gross settlement system* operates on a real-time basis, where payments are settled and cleared immediately and irrevocably (RTGS). Gross settlement requires the banks to hold central bank reserves equal to the amount that will be transferred to the other bank. (We assume that there are no overdraft facilities.) Since the total transfers made every period are constant and equal to t, banks have to hold t reserves in each period. In a *net settlement system*, incoming and outgoing payments are cleared at the end of the day, and only the net liabilities are transferred. The banks send and receive transfers of t. As long as there is no failure, no reserves are needed in order to settle.

We assume that a gross and a net settlement system are already in operation. The two banks can only use the net settlement system if they both agree to participate in it;

i.e. one party cannot unilaterally send payments through a netting system. Moreover, net settlement has to be approved by the supervisors. Transfers are therefore only netted out if both supervisors and private banks agree upon it.

The Bankruptcy Rule We need to define a bankruptcy rule that determines the payment obligations of the two netting partners in the case that one of them defaults. We assume that banks are always obliged to fulfill their settlement obligations to the other bank, regardless of whether the counterparty has declared bankruptcy or not.[4] We furthermore assume that depositors' claims on a bank's assets are senior to claims from the other bank. If a bank is not able to fulfill its payment obligations to either the depositors or to the other bank, it has to declare bankruptcy. These rules imply: (1) a failure of a bank's risky technology leads to bankruptcy of this bank, and (2) in the netting system, the other bank (if it itself is not bankrupt) is obliged to transfer t to the failing bank, which the receiving bank then will use to pay to its customers. Because the transfer t needs to be made only if one of the parties defaults, but otherwise nets out against incoming payments, we refer to it as the *Additional Settlement Obligation* (ASO). In a gross settlement system, there is no ASO because settlement always occurs immediately.

Supervision and Regulation In each country, a local supervisor (LS) is in charge of banking supervision. At time 0, the supervisor in country i, LS_i, can observe perfectly the local bank's type, q_i, but it receives no information about the foreign bank's type, q_j.

The local supervisors decide jointly about banks' access to the net system. Only if both supervisors agree, the banks in both countries are allowed to settle on a net basis. Otherwise, they have to use the gross settlement system. The supervisors decide upon access to the payment system as to maximize local welfare. Welfare-maximizing access regulation, however, depends on the risk of both the local and the foreign bank, i.e. on the information gathered by both supervisors. The supervisors

[4] We could instead have assumed that the banks are only liable for the net amount of outstanding payments (so-called 'netting by novation'). For financial contagion to occur, we would then need to assume non-balanced payment streams such that a failing bank could have net liabilities.

have therefore incentives to exchange information about the risk of the private banks. We model the information exchange in the following way: Before the game starts (e.g. at time $T = -1$), the supervisors agree upon a scheme that decides for which (q_1, q_2) net settlement should be allowed. At this stage there is no conflict of interest as the countries are identical before the risks are realized. The supervisors therefore choose the scheme that maximizes the expected welfare of the countries. Afterwards, the regulatory game is as follows: (1) The private banks apply to settle on a net basis, (2) The supervisors report the local banks' type to each other. If the types are such that netting should be allowed according to the pre-negotiated scheme, the permission is granted. Otherwise, the banks use the gross system. We discuss the scheme and the regulatory game in more detail later.

We do not assume that there is deposit insurance as we are considering large-value payment systems. The transfers in these systems, which usually originate from corporate clients rather than single households, are very large. Deposit insurance, as it is in place in most countries, would therefore only cover a small fraction of the deposits in question.[5,6]

Information At time zero, the local bank and local supervisor can observe the local bank's type. We assume that the supervisors cannot observe the risk of the foreign bank. We consider two different scenarios regarding the private banks' information: in the first, the local bank does not receive any information about the foreign bank's type. In the second, it can perfectly observe the foreign bank's type. At time 1, supervisors, private banks, and customers receive a perfect signal about the success of the risky projects in both countries.

Assumption 1: *The customers observe the type of settlement system used at time 1.*

Assumption 1 implies that the customers observe the type of settlement system used

[5] In the euro-area, deposit insurance covers between 15.000 and 100.000 euros (see Masciandaro and Cappella 1999). However, the average size of cross-border customer payments in TARGET is roughly 1.300.000 euro (source: ECB Monthly Bulletin, December 1999).

[6] Deposit insurance would introduce no additional moral hazard problems in our model. Therefore, a full deposit insurance would increase the welfare in the netting system unambiguously, since bank runs would be eliminated. Details are available upon request.

by the banks only at the time when the signal about the return of the risky asset is received.[7] Our main results do not depend on this assumption, but it allows us to solve the model in closed form. We relax Assumption 1 in section 6.3.

The timing is summarized as follows:

	$T = 0$	$T = 1$	$T = 2$
morning	- bank and supervisor i observe q_i	- customers A transfer	- customers B transfer
	- banks apply to use net system	- gross system: settlement	- gross system: settlement
	- information exchange		
	- supervisors decide upon access		
evening	- customers A deposit	- risky returns observed	- risky returns realized
	- banks invest	- customers B deposit	- net system: settlement
		- net system: settlement	- customers B withdraw
		- customers A withdraw	

3. Gross and Net Settlement

3.1. The Customers

At time 0, when the deposit contract with the customers A is signed, neither the banks' types nor the settlement system are known. However, the risk incurred by the customers A when depositing in the bank depends on both these factors. The customers A therefore demand an interest rate, r, which compensates them for this risk. In the following analysis, we will see that in the base model, the interest rate does not affect the choice of settlement system. This allows us to solve the game backwards: First, the choice of settlement system is determined as a function of the banks' types. This is done in sections 4 and 5. Afterwards, we find the interest rate that ensures customers A a non-negative expected return on their deposits. The interest rate is derived in appendix B.

[7] Suppose the consumers could observe the settlement system before making transfers. The choice of settlement system contains information about the risk of the banks. The interest rate would therefore have to be contingent on the type of settlement system chosen to avoid that the consumers withdraw their deposits.

The OLG structure of the model implies that the banks use customers B's deposits to return the deposits to customers A. At time 2, the customers B are then paid back their deposits out of the returns from the risky technology. Customers B observe both the type of settlement system and the success of the risky technology in the two countries before depositing. The customers B do not deposit in a bank with an unsuccessful technology, as the bank will not be able to return the deposits at time 2. In the following sections, it is discussed under which conditions the customers B invest in a bank with a successful technology. For now, notice: Customers B face no uncertainty about the value of the bank's assets. Hence, *if* the customers B deposit in the bank, they demand zero interest rate, as they are certain to be repaid.

3.2. Gross Settlement

In a gross settlement system, the banks need to hold t reserves every period to be able to settle all outgoing transfers. The banks use the deposits of customers B to pay customers A. The customers B deposit only 1, but the banks have to pay $1+r$ to customers A. Hence, in the first period, the banks hold additional r reserves on top of the settlement requirements. At time 0, banks thus must invest at least $t+r$ into reserves to be able to fulfill its obligations to the customers A at time 1. For now, assume that the remaining $1-t-r$ are invested into the risky technology. In appendix C, we show that this is the profit maximizing portfolio choice in equilibrium.

If customers B deposit, customers A withdraw $1+r$ at time 1. Each bank holds then t in reserves and $1-t-r$ in the risky asset. If the project is successful, the banks have $(1-t-r)R+t$ at time 2. Therefore, customers B deposit if and only if the technology is successful and

$$(1-t-r)R+t \geq 1 \tag{3.1}$$

We assume that (3.1) holds.[8] If the risky technology is unsuccessful, customers B do not deposit, as the bank cannot return the deposit at time 2. The bank is then forced into bankruptcy at time 1, because it cannot pay $1+r$ to customers A. Since the

[8] If (3.1) does not hold, the banks cannot invest in the risky technology when settlement is done on a gross basis. Welfare and profits are then trivially equal to zero.

liquidation value of an unsuccessful technology is zero, the customers A only receive the reserves that the bank holds, $t + r$.

For known q_i, bank i's expected profits in the gross system are

$$\pi_G^i(q_i) = (1 - q_i)[(1 - r - t)R - (1 - t)]. \qquad (3.2)$$

The expected welfare is

$$W_G^i(q_i) = (1 - t - r)\left[(1 - q_i)R - 1\right]. \qquad (3.3)$$

The higher the value of transfers, t, the less efficient is gross settlement, since less can be invested in the more profitable risky technology. Similarly, welfare and profits are decreasing in the interest rate, because of the additional reserves that the bank needs to hold, while they are increasing in the return on the risky technology.

Welfare and profits do not coincide because of limited liability and because the customers face informational constraints. The bank does not take into account the loss incurred by the customers if the bank fails, as it faces limited liability. If the customers observed the banks' types and the settlement system chosen, they would demand an interest that would reflect the true risk incurred when depositing in the bank. The interest rate would make the bank internalize the losses of the customers, and welfare and profits would be aligned. Here, however, the customers observe neither the settlement system chosen nor the risks of the banks. Hence, they cannot adjust the interest rate to the risk, and this drives in a wedge between public and private interests. We would like to emphasize, as discussed in section 6.3, that welfare and profits still would not coincide if the customers observed the settlement system but not the types of the banks.

3.3. Net Settlement

In a net settlement system, banks do not need to hold reserves for settlement purposes. They still have to hold r to pay the customers A the promised interest rate. As before, we assume that the remaining $1 - r$ is invested in the risky technology. In appendix C this is shown to be optimal in equilibrium.

Suppose that the risky technology of one of the banks fails. The bank with the low return goes bankrupt because the customers B do not deposit. The profits of the other bank are adversely affected as well because of the Additional Settlement Obligation (ASO). Following our assumptions, ASO is equal to t. The bank holds only r reserves, which it has to pay to the customers A at time 1. To pay (parts of) ASO, it is necessary to liquidate $Min\{1-r, \frac{t}{L}\}$ of the risky technology. Our analysis depends crucially on whether the bank can repay the customers B after liquidating some of the risky technology. If the bank cannot repay the customers B, these do not deposit, and all of the risky technology is liquidated to pay the customers A. This is the case of "*Full Contagion*". On the other hand, if the bank is able to repay the customers B, these will deposit, and the bank survives. We refer to this case as "*Partial Contagion*".[9] Partial Contagion (PC) occurs if and only if[10]

$$(1 - r - \frac{t}{L})R \geq 1. \tag{3.4}$$

Assumption 2: *There is Partial Contagion.*

The case of Full Contagion will be discussed in section 6.1. Under Partial Contagion, a bank will make positive profits if its own risky technology is successful (and zero profits if it isn't). Profits are highest if the other bank also succeeds. For given q_i, q_j, the expected profits of Bank i trading with Bank j are given as:

$$\pi_N^i(q_i, q_j) = (1 - q_i)\left[(1 - r)R - 1\right] - (1 - q_i)q_j t\frac{R}{L}. \tag{3.5}$$

We see that with net settlement, the foreign bank's failure rate q_j is crucial for expected profits: A high counterparty risk reduces profits of participating in the netting system because there is a high probability that a bank has to pay the Additional Settlement Obligation, t, to the failing bank. Profits increase in the liquidation value of a successful project, since it reduces the fraction of the risky technology that needs to be liquidated to pay ASO.

The expected welfare of country i is:

$$W_N^i(q_i, q_j) = (1 - r)\left[R(1 - q_i) - 1\right] - t\left[(1 - q_i)q_j\frac{R}{L} - q_i(1 - q_j)\right]. \tag{3.6}$$

[9] 'Full' and 'Partial' Contagion correspond to de Bandt and Hartmann's (1999) classification of 'weak' and 'strong' contagion.

[10] Notice that condition (3.4) also implies that the consumers B deposit in the gross system when the return is high.

In the case of failure, customers A receive only r from the local bank. In addition to this, the customers receive t (ASO) from the foreign bank if it survives.

4. Public Regulation

In this section we characterize the supervisors' regulation of access to the net settlement system. First, we assume that the supervisors observe both the type of the local and of the foreign bank (symmetric information). This serves to illustrate the preferences of the supervisors and to explain some of the effects driving the model. Afterwards, we turn to the complete model where supervisors observe only the local bank's type and must exchange information about the types to regulate efficiently (local supervision).

In order to present the communication between the supervisors as clearly as possible, we assume that the private banks always propose net settlement. The supervisors then decide how payments should be settled, as there is net settlement if they accept the proposal and gross settlement if they reject it. In section 5, we analyze the strategic interaction between the private proposal and the public regulation.

4.1. Benchmark: Symmetric Information

We analyze the outcome if the supervisors receive a perfect signal about the risk of the local and of the foreign bank. We assume that the supervisors are interested in maximizing their own country's welfare when deciding between net and gross settlement.

Define $\Delta W^i(q_i, q_j)$ as the welfare gain of Country i if there is net settlement instead of gross settlement:

$$\begin{aligned} \Delta W^i(q_i, q_j) &\equiv W_N^i(q_i, q_j) - W_G^i(q_i) \\ &= t(R-1)(1-q_i) - q_j t\left(q_i + (1-q_i)\frac{R}{L}\right) \end{aligned} \tag{4.1}$$

$\Delta W^1(q_1, q_2) = 0$ and $\Delta W^2(q_2, q_1) = 0$ are displayed in Figure 4.1(a). $\Delta W^i(q_i, q_j) = 0$ divides the (q_i, q_j)-space into two regions. Below the curve, net settlement maximizes the welfare of Country i, while gross settlement maximizes welfare above the curve.

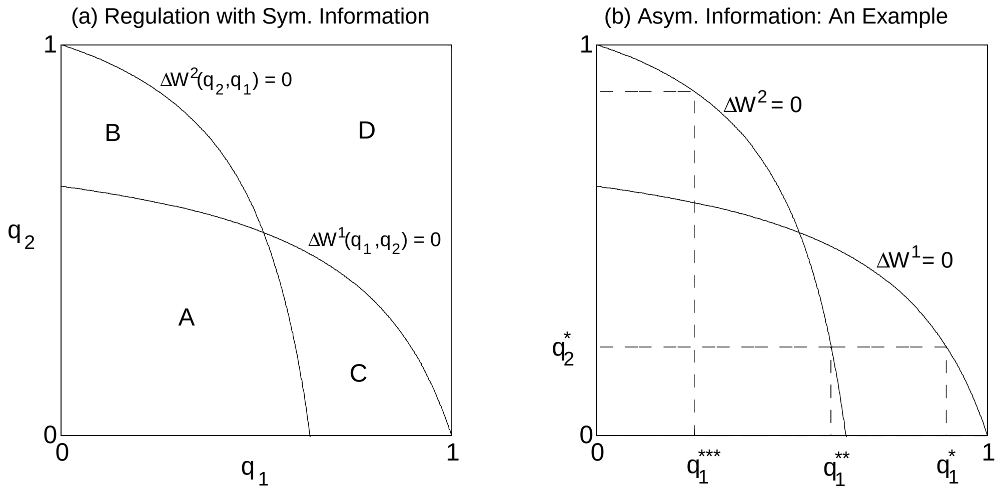

Figure 4.1: *The Supervisors' Preferences over the Mode of Settlement*

The supervisors allow net settlement only if the risk of the foreign bank is not too high. This is due to the basic trade-off between gross and net settlement systems: If the foreign bank is risky, gross settlement is the preferable mode of settlement, since it eliminates the risk of contagion. On the other hand, if the foreign bank is relatively safe, net settlement is optimal because reserve requirements are lower.

$\Delta W^i = 0$ is downward sloping because the investment in the risky technology is larger under net than under gross settlement. Therefore, as the probability of failure of this technology increases, welfare in the net system decreases more than in the gross system. In order to keep indifference between net and gross settlement, the foreign bank must be of a lower risk type.

Figure 4.1(a) illustrates how the interests of the two countries do not completely coincide. In the regions A and D, both countries prefer a net and a gross settlement system, respectively. In region B (C), however, the supervisor of country 1 (2), in which the bank with the lower risk is located, prefers gross settlement, while the one in country 2 (1) prefers the net system. The supervisor of the country with the lower risk is more reluctant to use net settlement, as it is relatively more likely to pay ASO than to receive it.

4.2. Local Supervision

From now on we assume that there is local supervision and the supervisors observe only the local bank's type. As an introductory example, consider Figure 4.1(b). The private bank in country 1 is of type q_1^*. We look at the incentives of the supervisor in Country 1 (LS_1) to reveal this information truthfully to the foreign supervisor (LS_2). LS_1 maximizes local welfare, so he would prefer net settlement whenever the foreign bank is of a type lower or equal to q_2^*. However, if LS_1 revealed the type q_1^* truthfully, LS_2 would never allow net settlement. Therefore, LS_1 would have incentives to try to induce the belief that the bank was of type q_1^{**}. (The local bank would then be allowed to use the net system for all types lower than q_2^*.) Suppose instead that LS_1 could only choose between revealing the true type, q_1^*, or inducing the belief q_1^{***}. Here, LS_1 would reveal the type truthfully, as LS_2 otherwise would allow net settlement too often.[11]

The example shows that since the interests of the supervisors are not totally aligned, the supervisors have incentives to induce a belief that is different from the bank's true type. Still, as the incentives of the supervisors are somewhat aligned, they do not want to induce beliefs that are too different from the true type. We will show next that this facilitates the information exchange between the supervisors.

4.2.1. The Information Exchange

Both the local and the foreign bank's type matter when the supervisors have to decide between a gross and a net settlement system. To regulate the international payment system efficiently, the supervisors have incentives to exchange information about the private banks' risks. We have in mind a situation where the national supervisors are sovereign and are not directly subject to any international authority. Therefore, we will assume it is not possible to set up a mechanism or an institution that can use transfers to extract the information about the private banks' types. Instead, we

[11] If the LS_2 believed that the bank in country 1 was of type q_1^{***}, he would allow net settlement for all types lower than q_2^{**}. The foreign bank's expected type given net settlement would thus be $\frac{1}{2}q_2^{**}$. Since $\frac{1}{2}q_2^{**} > q_2^*$, LS_1 would prefer to reveal the type truthfully. A similar example, explained in more detail, is given in section 4.3.

model the information exchange in the spirit of "cheap-talk": The supervisors can costlessly signal the risk of the private banks through written or oral communication, but they only volunteer this information truthfully (or, parts of it) if it serves their own interests. The existing literature analyzing signalling games with costless signals look at situations with one sender and one receiver (see, e.g., Crawford and Sobel (1982), Melumad and Shibano (1991), and Stein (1989)). We extend the analysis to the case of two-sided communication where both parties send and receive signals. The results obtained in this section are thus of some independent interest.

The information exchange is modelled the following way: At $T = -1$, before the banks' types are realized, the supervisors agree upon a binding scheme that maps the signals sent by the supervisors into acceptance or rejection of the proposal of net settlement. This scheme maximizes expected welfare.[12] At $T = 0$, after the risks have been realized, the supervisors send a signal about the local bank's risk. Once the signals have been sent, the settlement system is given by the scheme.[13] The information received from the foreign supervisor is confidential, and supervisors do not pass this information on to the private banks.[14]

There exists, of course, an incentive compatible scheme where the supervisors agree always to implement either a gross or a net settlement system. Proposition 1 characterizes the scheme when the information exchange matters for the choice of settlement system. Invoking the revelation principle, we restrict attention to incentive compatible schemes. We consider only schemes that are piecewise continuous, symmetric, and specify (as a function of q_i) the maximal type of the foreign bank for which net settlement is allowed.

[12] Alternatively we could assume that a welfare-maximizing supranational regulator decided upon access to the net system. As long as he could not use transfers to extract the information of the local supervisors, he would choose the same scheme as the one implemented by the local supervisors.

[13] Since the signals are binding, it is not formally a 'cheap-talk' game. We show in Corollary 1 that the schemes derived are also incentive compatible with non-binding signals.

[14] We need this assumption to ensure that the private banks always invest as much as possible in the risky technology. However, this assumption is not crucial for our results. We show in Appendix C that if signals were non-binding, the assumption would not be necessary as the supervisors would exchange less information about the private banks' types.

Proposition 1. *Suppose the foreign bank's risk is uniformly distributed between* 0 *and* $\overline{q}$. *An incentive compatible scheme,* $\Phi^n(\cdot)$, *defines for each local risk* q_i *the maximal foreign risk* q_j *for which transfers are settled in a net system.* $\Phi^n(\cdot)$ *is characterized as follows:*

1. $\Phi^n(\cdot)$ *consists of* n *intervals,* $n \geq 2$. *Let interval* z, $1 < z \leq n$, *be defined as* $I_z \equiv (q^n_{z-1}, q^n_z]$ *with* $q^n_{z-1} < q^n_z$ *and* $q^n_n = \overline{q}$. *Interval* 1 *is defined as* $I_1 \equiv [0, q^n_1]$.

2. $\Phi^n(\cdot) = q^n_{n-z}$ *for* $q_i \in I_z$, *where* $1 \leq z \leq n$ *and* $q^n_0 = 0$.

3. $\{q^n_1, q^n_2, ..., q^n_{n-1}\}$ *are given as the solution to the following system of equations:*

$$\begin{aligned} \Delta W^i\left(q^n_{n-1}, \frac{1}{2}q^n_1\right) &= 0 \\ \Delta W^i\left(q^n_{n-2}, \frac{1}{2}\left(q^n_1 + q^n_2\right)\right) &= 0 \\ &\vdots \\ \Delta W^i\left(q^n_1, \frac{1}{2}\left(q^n_{n-2} + q^n_{n-1}\right)\right) &= 0 \end{aligned}$$

The schemes with two and with three intervals are shown in Figure 4.2. Under these schemes, the supervisors reveal the banks' types truthfully, and the banks settle in the net system whenever $q_j \leq \Phi^k(q_i)$, $k \in \{2, 3\}$.

There are several things to notice about the schemes. First, since the two supervisors face the same scheme, it must be symmetric around the 45-degree line.[15] Second, a scheme consists of constants segments with "jumps". The example in the previous section illustrated how the supervisors would have incentives to report a type that is not the true one, but close. Along the constant parts of the scheme, it makes no difference to tell such a 'small lie'. The constant parts are thus necessary for the scheme to be incentive compatible. Finally, notice that the schemes are symmetric around $\Delta W^i(q_i, q_j) = 0$ at the jumps. This implies that if the local bank is located at the border to the next interval (i.e. at a jump), the supervisor is exactly indifferent between being in the lower or in the upper interval. We show that this ensures that if the local bank is of a type located close to a jump, the supervisor does not want to tell a small lie in order to pretend to be in the nearby interval (and do net settlement with a different population of the foreign bank).

[15] Otherwise, there would exist some (q_i, q_j) for which the scheme would indicate net settlement for one bank but not for the other.

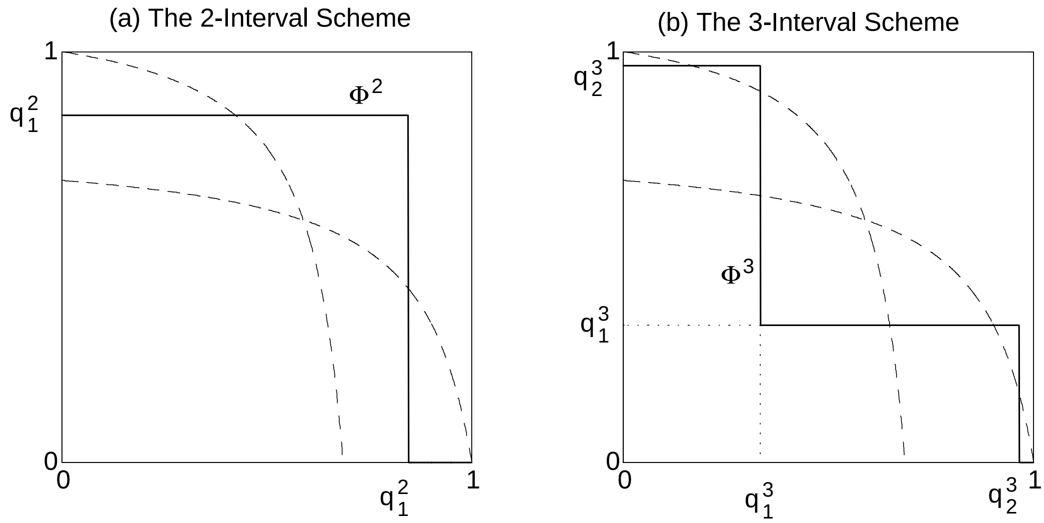

Figure 4.2: *Incentive Compatible Schemes*

The constant parts and the jumps are sufficient to rule out profitable deviations where the supervisors tell a small lie. In the proof of Proposition 1, we show that the supervisors neither have incentives to tell a 'big lie' and report a type that is far from the true one. The scheme satisfies this condition because, as illustrated by the example, the banks do not wish to induce beliefs too different from the true type.

We have chosen to focus on the case of binding signals, as it allows for a mechanism where the supervisors report the banks' true types. The next corollary shows that the results obtained do not depend upon whether signals are binding or not. If signals were non-binding, the supervisors would first send the signals. After having received the signal, the supervisors would unilaterally decide whether to accept net settlement. Corollary 1 shows that any scheme characterized by Proposition 1 would also be incentive compatible with non-binding signals. The only difference would be that instead of reporting the type, the supervisors would report the interval to which the local bank belongs. The game with non-binding signals is explained in more detail in the proof of the corollary.

Corollary 1. *The schemes characterized by Proposition 1 are also incentive compatible with non-binding signals.*

Finally, we make one additional assumption:

Assumption 3: *If a supervisor received no information about the foreign bank's type, he would never allow net settlement.*

Our results do not hinge on this assumption, but it allows us to restrict attention to the simplest of the possible cases. We relax Assumption 3 in section 6.2.

Proposition 2. *Consider the schemes defined by Proposition 1. Under Assumption* 3 *there exist an unique incentive compatible scheme with two intervals and none with more than two intervals.*

From Proposition 2 then follows that we only need to consider schemes with either one interval (i.e. always accept or reject the proposal of net settlement) or with two intervals.

4.3. The (In)Efficiency of Public Regulation

The previous section has shown how the supervisors face incentive problems when exchanging information about the private banks' risk. In this section we analyze the implications this has for public regulation.

As a first result, we show that the information exchange does make a difference. In spite of the incentive problems, the supervisors regulate more efficiently if they communicate. Formally, the proof consists of showing that the expected welfare under the two interval scheme is higher than if the banks would do either net or gross settlement for all types.

Lemma 1. *The scheme with two intervals gives higher expected welfare than the schemes with one interval.*

In order to determine the efficiency of the public regulation, we compare the scheme with the two-interval scheme that would be implemented if there were no incentive problems. This is the two interval scheme that maximizes expected welfare ex ante; i.e. before the banks' types are realized.[16] A two interval scheme would, of course, not be optimal if there were no incentive problems, but the comparison tells us whether the access regulation to the net settlement system is too strict or too lax.

[16] Since both countries are ex-ante identical it does not matter whether we refer to local or global welfare.

Proposition 3. *Suppose there were no incentive problem but the supervisors could only implement schemes with two intervals. The maximal type for which the supervisor would allow net settlement would be strictly smaller than* q_1^2.

Proposition 3, which is the main result of this paper, shows that the incentive problems in the information exchange induce the supervisors to be too lax in their access criteria to the net settlement system. As a result, the systemic risk under public regulation is higher than optimal.

The intuition behind this result is given by Figure 4.2(a). In equilibrium, net settlement is allowed if both banks are of a type lower or equal to q_1^2. Consider the problem faced by a supervisor when signalling the local bank's type. If he signals a type lower than q_1^2, there will be net settlement whenever the foreign bank is of a type lower than q_1^2. If, instead, the supervisor signals a type higher than q_1^2, there will be gross settlement. Therefore, the signal sent by the supervisor makes only a difference if the foreign bank is of a type lower or equal to q_1^2. Hence, the supervisor compares the expected welfare under gross and net settlement conditional on the foreign bank being of a type lower or equal to q_1^2. This is equivalent to comparing the welfare under net and gross settlement assuming that the foreign bank is of the *average* type, $\frac{1}{2}q_1^2$.[17] Since the supervisors base their decision on the average type, they allow net settlement for realizations where they would have preferred gross settlement. For example, if the bank in Country 1 is of type q_1^2, there is net settlement also if $q_2 \in (\frac{1}{2}q_1^2, q_1^2]$ - even if both supervisors under these circumstances would have preferred gross settlement.

It is important to notice that the excessive systemic risk under public regulation does not reduce the surplus of the customers. The customers foresee the equilibrium outcome and ask for an interest rate which compensates them for the risk they incur. If the supervisors have too lax access criteria to the net settlement system, the customers ask for a higher interest rate as depositing in the bank is riskier. This reduces the profits for the banks because fewer reserves can be invested in the profitable long-run technology. In our model, the cost of excessive systemic risk is thus carried by

[17] This is true in this model since the types are uniformly distributed and welfare is linear in the foreign bank's type once the own type is known.

the banks rather than the customers.

5. The Private Banks

We turn now to the settlement decision of the private banks. In the previous section it was assumed that the private banks always propose net settlement. Therefore, the national supervisors could decide between gross and net settlement. The supervisors, however, cannot impose net settlement against the wishes of the private banks. It is thus left to be shown that the private banks propose net settlement in the region where the supervisors allow it.

The private banks move first in the regulatory game and propose how to settle payments. The private banks' proposal depends both on the regulation they foresee and on the information that they have about each other. The regulation by the supervisors was determined in section 4, so we turn here to the proposal made by the private banks under different informational assumptions.

The analysis of the private banks has three parts. First, we determine the preferences of the private banks over net and gross settlement. Afterwards, we solve the model assuming that the private banks have no more information than the supervisors. We show that the results derived under public regulation are the equilibrium outcome. It seems plausible that a bank operating internationally can have better information about its foreign counterparties than the national supervisor. Ideally the regulation of the payment system should be designed to take advantage of the private banks' information (see also Rochet and Tirole (1996)). This would be an argument for leaving the access regulation in the hands of the private sector, as it is, for example, currently done in European Monetary Union. In the last part, we thus examine whether superior information alone can justify a 'hands-off' approach to access regulation.

5.1. Gross and Net Settlement

Let us start by determining the banks' preferences over the mode of settlement. From (3.2) and (3.5), we derive a threshold, q^{PR}, for the foreign bank's risk such that bank

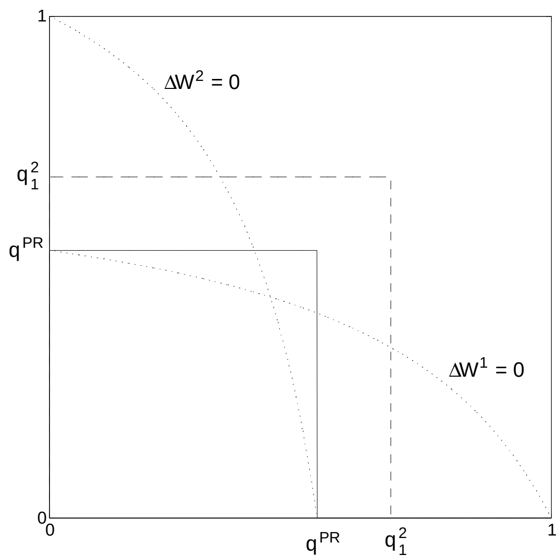

Figure 5.1: *The Private Banks' Preferences*

i is indifferent between gross and net settlement:

$$q^{PR} \equiv \frac{R-1}{R}L \tag{5.1}$$

A bank prefers to net out transfers only if its counterpart's risk of failure is smaller than q^{PR}; that is, if the probability of contagion is low. The important thing to notice is that a private bank's preferences do not depend on its own type. Since the bank faces limited liability, it earns zero profits if it fails itself. Consequently, the bank's own risk does not influence the choice between net and gross settlement.

As long as the local bank is successful, it carries the full cost of net settlement because it pays ASO if the foreign bank fails. The bank does not, however, take into account the loss experienced by customers if both banks fail. From point of view of welfare, the bank chooses net settlement too often unless it is sure not to fail. Figure 5.1 illustrates this point: q^{PR} is above $\Delta W^i = 0$ except for $q_i = 0$ where they coincide.

5.2. No Informational Advantage

Here we assume that neither the private banks nor the supervisors observe the risk of the foreign bank. Like the supervisors, the private banks can exchange information. The banks cannot decide whether to implement a net settlement system or not, as the netting must be approved of by the supervisors. Instead, we assume that the banks can agree upon a scheme that maps the signals sent into a proposal made to the supervisors (i.e. net or gross settlement). The analysis is similar to the one in section 4, so we have directed it to the appendix.

Proposition 4. *If the private banks have no more information than the national supervisors, the private banks do net settlement if and only if* $q_1, q_2 \leq q_1^2$.

The results derived in section 4 do hold as long as the private do not have better information than the supervisors. We show that private banks propose net settlement in a larger area than the supervisors allow. In equilibrium, the supervisors overrule the private banks' proposal whenever they propose net settlement and at least one of the banks is of type higher than q_1^2.

Notice that $q^{PR} < q_1^2$, so the private banks do net settlement more often than they would prefer (see Figure 5.1). However, they cannot agree on a scheme that proposes net settlement in a smaller area. The reason is that the private banks face more severe incentive problems in the information exchange than the national supervisors do. For the supervisors, the benefits of net settlement are decreasing in the risk of the local bank. The incentive to pretend that the local bank is of a low type is thus decreasing with the risk. In the case of the private banks, all types have the same incentive to pretend to be of a low type. This can also be seen in Figure 5.1 where $\Delta W^i = 0$ is downwards sloping while $\Delta \pi^i = 0$ (i.e. q^{PR}) is constant. As a result of this, the information exchange among the private banks is less efficient than the one among the supervisors, and the banks do net settlement whenever it is allowed.

5.3. Superior Information

We now consider the polar assumption that the banks receive a perfect signal about each others' type. The private banks then propose net settlement if they are both of a type lower than q^{PR}. The next proposition shows that given this information, the supervisors cannot exchange any additional information and they accept the private proposal.

Proposition 5. *Under symmetric information between the private banks, public regulation cannot improve upon the private proposal.*

Proposition 5 implies that if the private banks can observe each other's type, they decide the settlement method de facto. The national supervisors could overrule the private proposal, but in equilibrium they never do so. Under circumstances where the banks are likely to have good information about their counterparties, for example, because they operate internationally, this result gives some justification to leaving the access regulation in the hands of the private sector.

6. Extensions

In this section we relax Assumptions 1-3. We do not include the full analysis of the extensions, as most parts are similar to the base model. Instead, the following contains a discussion of the results obtained and points out the most important differences compared to the main text. The details of the analysis are available upon request. In all three extension, it is not possible to solve the model entirely in closed form, so we rely partly on numerical simulations.

6.1. Full Contagion

In the preceding section, we focused on the case where the failure of one bank did not lead to bankruptcy of the other bank (*Partial Contagion (PC)*). In this section, we turn to the other case of *Full Contagion (FC)* where a bank with a successful project is forced into bankruptcy if its counterparty in the netting system fails. Under Full Contagion, it is not possible to solve the model in closed form, since the scheme agreed upon by the supervisors and the interest rate are interdependent.

The failure of one bank in the netting system obliges the surviving bank to pay ASO to the failing bank. Full contagion occurs if the amount of assets that needs to be liquidated for this purpose is so large that customers B cannot get the promised payment of 1 at time 2.[18] As a consequence, customers B do not deposit, and the bank must liquidate its entire technology in order to pay the proceeds to customers A. Thus, the bank fails at time 1. Since the claims of customers A are senior to those of the other bank, the value of the liquidation goes to the customers only, and the

[18] We are thus in the case of Full Contagion for low L (many assets need to be liquidated), low R (time 2 return gets small), and high t (high ASO).

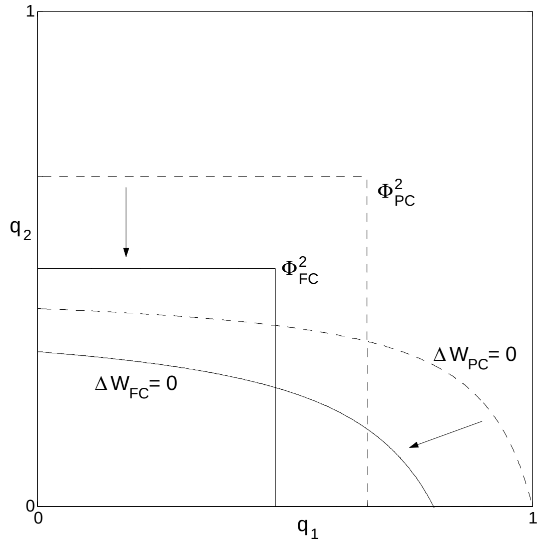

Figure 6.1: *From Partial to Full Contagion*

additional settlement to the other bank is not paid.

This implies that in the net system, the banks earn positive profits only if they both are successful. Profits and welfare are given as:

$$\pi^i_N(q_i, q_j) = (1 - q_i)(1 - q_j)[(1 - r)R - 1]. \tag{6.1}$$

$$W^i_N(q_i, q_j) = (1 - r)\left[(1 - q_i)(1 - q_j)R + (1 - q_i)q_j L - 1\right]. \tag{6.2}$$

Notice that under *FC*, the size of the additional settlement obligation, t, affects neither profits nor welfare directly since it is never paid.[19] Hence, both countries are worse off under *FC* compared to *PC*: the country of the failure's origin because it does not receive *ASO*, and the other country because the bank goes bankrupt. Net settlement is therefore less attractive under *FC*. In a gross system, expected profits and expected welfare are as under *Partial Contagion*. We define $\Delta W^i_{FC}(q_i, q_j) \equiv W^i_{N,FC}(q_i, q_j) - W^i_G(q_i, q_j)$.

Figure 6.1 illustrates how the preferences of the supervisors change as we switch from *Partial* to *Full Contagion*. The welfare under net settlement is reduced discretely as we enter the region of *FC*. Hence, the region in which net settlement is preferred diminishes (the $\Delta W^i = 0$ curves jump inwards). As a result of this, public regulation

[19] t has an indirect effect via the interest rate. However, at the time the decision about settlement is made, the interest rate is fixed.

becomes more restrictive. Figure 6.1 shows how the highest type that is allowed in the net settlement system is reduced from $q^2_{1,PC}$ to $q^2_{1,FC}$.

Let us now turn to the private banks. Comparing equations (3.2) and (6.1), we find that bank i wants to net out transfers with bank j if and only if $q_j < q^{PR}_{FC}$ where

$$q^{PR}_{FC} = \frac{t(R-1)}{(1-r)R-1}. \tag{6.3}$$

Consider again a set of parameters marking the border between Full and Partial Contagion. While the expected local welfare is reduced discretely, the change in the banks' expected profits is gradual. Starting in the region of PC and approaching the border to FC, the profits of the local bank go to zero in the state of the world where the bank has to pay ASO. On the border, and in the region FC, the profits are zero in this state of the world. As there is no discontinuity in the profits from PC to FC, there is no discontinuity in q^{PR}.

Under *Full Contagion* the problem of banks' limited liability is more serious than it was under *Partial Contagion*: Even if only one of the banks fails, customers A receive less than the promised amount of $1+r$ (under PC this was the case only if both banks failed). The banks disregard the welfare of the customers and propose net settlement for too high risks. Because the welfare cost of net settlement is higher under *Full Contagion*, the wedge between private and public interests is wider. Therefore, the supervisors might overrule the private proposal also if the private banks have perfect information about each others' types; unlike under *Partial Contagion*. The case for active public involvement in access regulation is thus stronger if the systemic impact of a foreign failure is high.

6.2. Schemes With More Than Two Intervals

Assumption 3 was a very convenient assumption, as it allowed us to focus on the simplest case where no incentive compatible schemes with more than two intervals existed. If the private banks observe each others' type (Superior Information), a relaxation of Assumption 3 does not change the results. The private banks will as before decide the mode of settlement.[20] But, if the private have no more information

[20] The reader can verify that the proof of Proposition 5 does not make use of Assumption 3.

than the supervisors (No Informational Advantage), relaxing Assumption 3 changes the analysis of the game, but not necessarily the equilibrium outcome.

Suppose from now on that neither the private banks nor the supervisors observe the foreign bank's type. We first consider the case where the private banks always propose net settlement.[21] Here, the supervisors decide whether the banks should net out transfers or settle them in the gross system. We obtain the following result about the public information exchange:

Lemma 2. *If Assumption 3 does not hold, there exist unique incentive compatible schemes with two and with three intervals.*

Numerical simulations show that there cannot exist an incentive compatible scheme with 4 intervals. It is possible to show that this implies that there cannot exist schemes with more than four intervals either. Therefore, the supervisors can exchange information using either a two or a three interval scheme (Φ^2 and Φ^3, respectively). Figure 4.2 illustrated these schemes. The supervisors choose Φ^2 for most values, as it gives the highest expected welfare. However, for high R, it is Φ^3 that approximates the preferences of the supervisors best and is the optimal choice.

Suppose now that the private banks exchange information. The scheme that the private banks agree upon has the following general form: The private banks propose net settlement if and only if at least one of the banks is of a type lower or equal to $\widetilde{q}^{PR}$. Let us first consider the candidate equilibrium where the supervisors afterwards agree upon Φ^3. It can be shown that foreseeing Φ^3, the private banks propose net settlement in a strictly larger area than Φ^3. The three interval scheme is therefore as defined by Proposition 1, and the supervisors sometimes overrule the private proposal. This candidate equilibrium is illustrated in Figure 6.2(a) where the private scheme is denoted Φ_3^{PR}.

Alternatively, the supervisors can agree upon a two interval scheme. Here, the private and the public scheme overlap. As a result, the public two interval scheme given by Proposition 1 is not incentive compatible. Instead, the private and the public scheme must be determined simultaneously. Denote the public scheme obtained by $\widetilde{\Phi}^2$. $\widetilde{q}_1^2$

[21] As in the base model, it is never optimal for the private banks always to propose gross settlement.

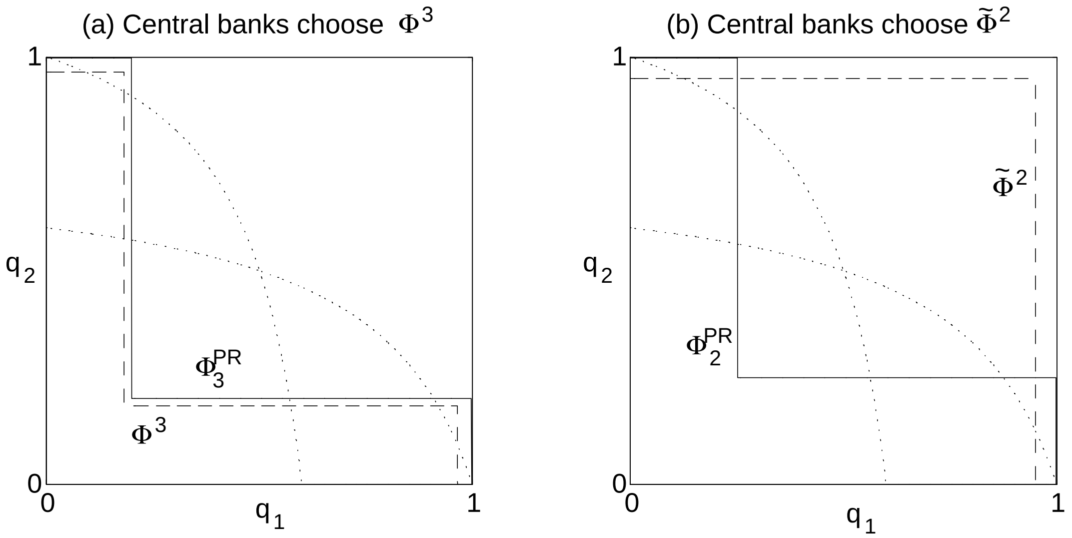

Figure 6.2: *The Equilibrium Exchange of Private Banks and Supervisors*

is the border between the first and the second interval of the public scheme. This candidate equilibrium, which is illustrated in Figure 6.2(b), works the following way: The private banks propose net settlement if one of the banks (or both) is of a type lower or equal to $\widetilde{q}_2^{PR}$. The private proposal is accepted only if both banks are of a type lower or equal to $\widetilde{q}_1^2$.

We see that the supervisors can also choose between a two and a three interval scheme if the private banks exchange information (even though the two interval scheme is different). It turns out that the two interval scheme is optimal for the supervisors. If the private banks exchange information, the supervisors respond by using the scheme $\widetilde{\Phi}^2$.

Let us consider the equilibrium of the full game. The private banks move first and decide whether to exchange information or not. Numerical simulations show that the private banks prefer Φ^2 to $\widetilde{\Phi}^2$. As long as the supervisors choose Φ^2 rather than Φ^3, it is thus the subgame perfect equilibrium that the private banks always propose net settlement. This equilibrium is the same as in the base model. However, the private banks prefer $\widetilde{\Phi}^2$ to Φ^3. For high R, where the supervisors would choose Φ^3 if the private banks always proposed net settlement, the private banks exchange information in order to induce the supervisors to play the scheme $\widetilde{\Phi}^2$ instead of Φ^3.

6.3. Contingent Interest Rates

We have assumed throughout the paper that customers observe the type of settlement system used only at time 1. In this section we relax this assumption. Customers now demand an interest rate that is contingent on the type of settlement system implemented. We are interested in whether contingent interest rate eliminates the wedge between profits and welfare. Because of computational complexity, most results derived here are numerical.

It is not a priori clear whether the interest rate is highest in the gross or in the net settlement system, as there are two effects at play. First, the customers know that if their bank is in a gross settlement system, the higher reserve holdings imply that it returns a larger share of the deposit if it fails. This effect goes in the direction of a lower interest rate in the gross settlement system. Second, the customers update their beliefs about the banks' types after having observed the mode of settlement. Gross settlement is a bad signal about the bank's type, since at least one of the banks must be of a high risk type. This effect implies a higher interest rate in the gross system as to reflect the higher probability of failure. The numerical analysis shows that the second effect usually dominates. For most parameter values, the interest rate in the gross system is higher than the one in a net system.

Denote the interest rates in the gross and net system by r_G and r_N, respectively. The gain in welfare and profits from netting are now

$$\Delta W_i = (t + r_G - r_N)\left[(1-q_i)R - 1\right] + q_i t - q_j t\left[\frac{R}{L}(1-q_i) + q_i\right],$$

$$\Delta\pi_i \equiv \pi_N(r_N) - \pi_G(r_G) = (1-q_i)\left[(r_G - r_N)R + t\left(R - 1 - q_j\frac{R}{L}\right)\right].$$

A spread in the interest rates $r_G > r_N$ increases the amount of reserves that must be held under gross settlement relative to net settlement. Hence, if the interest rates are contingent on the mode of settlement, net settlement becomes more attractive. The region with net settlement is larger than in the base model. Notice that $\partial\Delta W_i/\partial(r_G - r_N) < \Delta\pi_i/\partial(r_G - r_N)$. The spread in interest rates has a larger effect on the private choice on how to settle than it has on the public one.[22] Therefore, the supervisors

[22] The higher interest rate in the gross system increases the welfare of the consumers in the state

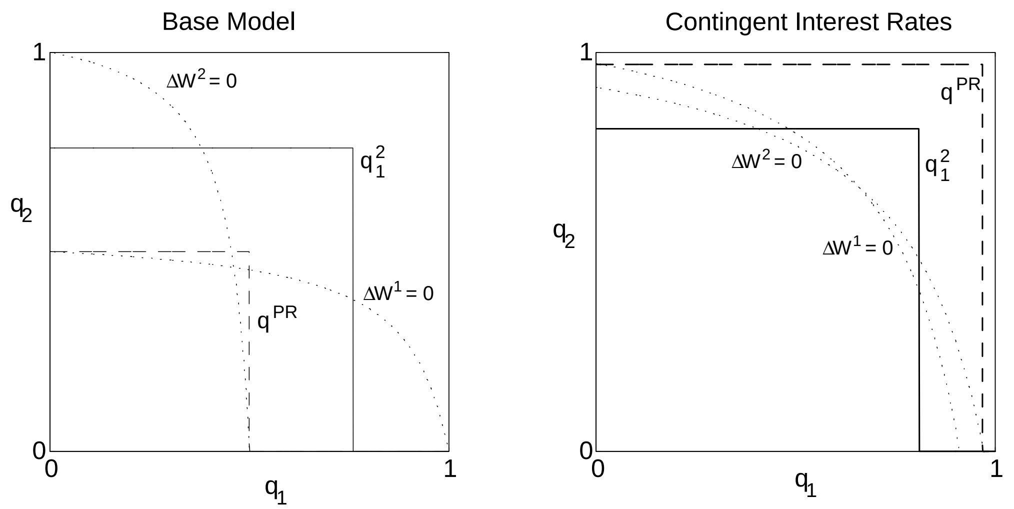

Figure 6.3: *Contingent vs. Non-Contingent Interest Rates*

might overrule the private proposal of net settlement even if the private banks observe each others' type.

As an example, consider Figure 6.3 where the public and private preferences are displayed for the same set of parameter values. The region of netting is larger with contingent rates, independently of who decides upon the mode of settlement. The difference is greatest for the private preferences.

The numerical analysis verifies that with contingent interest rates, banks' profits still do not coincide with welfare. The intuition is, as explained earlier, that the interest rate does not reflect the true risk, since the customers do not observe the banks' types. Thus, contingent interest rates are not enough to eliminate incentive problems in access regulation.

7. Conclusion

In this paper, we have analyzed the regulation of access to international large-value payment systems when supervision of the banking industry is a national task. We modeled the regulator's decision to provide access to gross and net settlement systems.

of the world where the two banks fail. This is not taken into account by the private banks. For the private banks, the relative attractiveness of net settlement thus increases more in $r_G - r_N$ than it does for the supervisors.

As a novel feature, the communication between the national supervisors about the private banks' risk was endogenized. Furthermore, we studied the outcome that private banks would choose if they were not subject to regulation, and compared the efficiency of publicly and privately regulated systems.

Both the public and private solutions are shown to be inefficient, since too risky banks are allowed into the netting systems. Systemic risk is therefore higher than desirable. Unregulated private systems are too risky because banks face limited liability. Banks do therefore not take into account the full cost of bankruptcy. The inefficiency of the publicly implemented system stems from national supervision. The national supervisors' incentives are not perfectly aligned, because the foreign economy carries some of the costs of failure in a net settlement system. Therefore, the local supervisors have incentives to understate the risk of the local bank to induce net settlement in cases where the foreign economy would prefer gross settlement.

We find that if the private banks have the same information as the public authorities, the decision about the mode of settlement should be made by the public regulator. However, if the private banks possess superior information about the foreign bank's risk, say, because of a high degree of integration in financial markets, it can be efficient to leave this decision to the private banks. Private access regulation does especially well in terms of welfare if the systemic impact of a failure is low, as the private banks internalize most of the costs of net settlement. On the other hand, when failures propagate through the system, the customers bear most of the cost of the systemic crisis. Then, the case for public regulation is stronger.

Our model could be interpreted in view of the situation in the euro-area where international RTGS and netting systems coexist. It points out circumstances under which a "hands-off" policy should be followed with regard to payment system regulation. The framework could also be used to analyze domestic payment systems in which foreign banks participate. If these banks are subject to home-country supervision, similar communication problems can arise between host- and home country supervisors. Finally, the communication exchange modelled in this paper could be used to study the supervisory framework not only for payment systems, but more generally for international banking.

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A. Proofs of Propositions and Remarks

A.1. Proposition 1

We look for an incentive compatible scheme such that if a supervisor signals that the type of the private bank is q_i, he commits to settling on a net basis whenever the foreign supervisor signals $q_j \leq \Phi^n(q_i)$. For this scheme to be feasible, in the sense that all types settle net whenever the foreign bank has a risk lower than $\Phi^n(\cdot)$, $\Phi^n(\cdot)$ has to be *symmetric*: $\Phi^n(\cdot) = (\Phi^n)^{-1}(\cdot)$ for all $q \in [0, \overline{q}]$. Define $f_1(q_1)$ st. $\Delta W^1(q_1, f_1(q_1)) = 0$. It follows from (4.1):

$$f_1(q_1) = \frac{(1-q_1)(R-1)L}{q_1 L + (1-q_1)R} \tag{A.1}$$

and

$$(f_1)^{-1}(q) = \frac{(R-1)L - qR}{(R-1)L - q(R-L)}.$$

Step 1: $f_1(\cdot)$ *is not symmetric.*

Proof: For all $0 < L < 1$ and $R > 1$ we have that $f_1(0) < (f_1)^{-1}(0)$. $f_1(\cdot)$ is therefore not symmetric.

Step 2: $\Phi^n(q)$ *cannot be continuously increasing or decreasing on an open set.*

Proof: Suppose there exists some q st. $\Phi^n(q) < f_1(q)$. If $\Phi^n(\cdot)$ is strictly increasing, there exists some ε st. $\Phi^n(q) < \Phi^n(q+\varepsilon) \leq f_1(q)$. A supervisor with a private bank of type q will therefore have incentives to deviate and signal the type $q+\varepsilon$. On the other hand, if $\Phi^n(\cdot)$ is strictly decreasing, there exist some ε st. $\Phi^n(q) < \Phi^n(q-\varepsilon) \leq f_1(q)$. A supervisor with a private bank of type q will therefore have incentives to deviate. A similar argument applies to $\Phi^n(q) > f_1(q)$. If $\Phi^n(\cdot)$ is strictly in- or decreasing on an open set, it has to be that $\Phi^n(\cdot) = f_1(\cdot)$. However, as $f_1(\cdot)$ is not symmetric, this not a feasible scheme.

Step 3: *Suppose there is a discontinuity at q_i^n s.t. $\lim_{q \to (q_i^n)^-} \Phi^n(q) = q_{j+1}^n$ and $\lim_{q \to (q_i^n)^+} \Phi^n(q) = q_j^n$ and $q_j^n \neq q_{j+1}^n$. Then it has to hold:*

$$\Delta W^i \left(q_i^n, \frac{1}{2}\left(q_j^n + q_{j+1}^n\right) \right) = 0. \tag{A.2}$$

Proof: Incentive compatibility requires that all $q_i \in (q_{i-1}^n, q_i^n]$ prefer to settle net with all $q_j \leq q_{j+1}^n$, instead of doing net settlement only with $q_j \leq q_j^n$, while the opposite is true for $q_i \in (q_i^n, q_{i+1}^n]$. This leads to the following two incentive compatibility constraints:

$$\frac{\overline{q}-q_{j+1}^n}{\overline{q}} W_G^i(q) + \frac{q_{j+1}^n}{\overline{q}} W_N^i\left(q, \frac{q_{j+1}^n}{2}\right) \geq \frac{\overline{q}-q_j^n}{\overline{q}} W_G^i(q) + \frac{q_j^n}{\overline{q}} W_N^i\left(q, \frac{q_j^n}{2}\right) \ \forall\, q \in (q_{i-1}^n, q_i^n]$$

$$\frac{\overline{q}-q_{j+1}^n}{\overline{q}} W_G^i(q) + \frac{q_{j+1}^n}{\overline{q}} W_N^i\left(q, \frac{q_{j+1}^n}{2}\right) \leq \frac{\overline{q}-q_j^n}{\overline{q}} W_G^i(q) + \frac{q_j^n}{\overline{q}} W_N^i\left(q, \frac{q_j^n}{2}\right) \ \forall\, q \in (q_i^n, q_{i+1}^n].$$

Using (3.6) and (4.1), these constraints reduce to:

$$\left(q_{j+1}^n - q_j^n\right) \Delta W^i\left(q, \frac{1}{2}\left(q_j^n + q_{j+1}^n\right)\right) \geq 0 \ \forall\, q \in (q_{i-1}^n, q_i^n] \tag{A.3}$$

$$\left(q_{j+1}^n - q_j^n\right) \Delta W^i\left(q, \frac{1}{2}\left(q_j^n + q_{j+1}^n\right)\right) \leq 0 \ \forall\, q \in (q_i^n, q_{i+1}^n]. \tag{A.4}$$

(A.2) follows then from continuity of $\Delta W^i\left(q, \frac{1}{2}\left(q_j^n + q_{j+1}^n\right)\right)$. $\square$

Step 4: *Incentive compatibility requires* $q_j^n < q_{j+1}^n$.

Proof: $\Delta W^i\left(q_i^n, \frac{1}{2}\left(q_j^n + q_{j+1}^n\right)\right) = 0$ for $q_i^n > 0$ implies that

$$\frac{1}{2}\left(q_j^n + q_{j+1}^n\right) < \frac{(R-1)L}{R} \tag{A.5}$$

Suppose that $q_j^n > q_{j+1}^n$. (ICC1) then implies that $\Delta W^i\left(q, \frac{1}{2}\left(q_j^n + q_{j+1}^n\right)\right) \leq 0$ for all $q \in (q_{i-1}^n, q_i^n]$. Using (A.2), we can thus write (ICC1) as

$$\Delta W^i\left(q_i^n, \frac{1}{2}\left(q_j^n + q_{j+1}^n\right)\right) \geq \Delta W^i\left(q, \frac{1}{2}\left(q_j^n + q_{j+1}^n\right)\right) \ \forall\, q \in (q_{i-1}^n, q_i^n].$$

Solving this condition we obtain $\frac{1}{2}\left(q_j^n + q_{j+1}^n\right) \geq \frac{(R-1)L}{R-L}$, which contradicts (A.5). Similarly, it can be shown that if $q_j^n < q_{j+1}^n$, the scheme is incentive compatible for all $\frac{1}{2}\left(q_j^n + q_{j+1}^n\right) < \frac{(R-1)L}{R-L}$, which is satisfied. We have therefore shown that it is not optimal to deviate to a neighboring interval. It can be shown along the same lines that it is not optimal to deviate to any other interval. (A.2) and $q_j^n < q_{j+1}^n$ are therefore sufficient conditions for the scheme to be incentive compatible.

Step 5: *The system of equations in Proposition 1 characterizing* $\{q_1^n, q_2^n, ..., q_{n-1}^n\}$ *follows from symmetry of* $\Phi^n(\cdot)$, *(A.2), and* $q_1^n < q_2^n < ... < q_{n-1}^n$. $\square$

A.2. Corollary 1

If the signals are non-binding, the timing is the following: First the supervisors simultaneously send a signal about their type. Afterwards they decide simultaneously whether to accept or to reject net settlement. Net settlement is only implemented if both supervisors accept it.

In equilibrium, the supervisors do not signal the local bank's type but instead to which interval it belongs (see, e.g., Crawford and Sobel (1982) and Stein (1989)). Assume that the intervals are given by Proposition 1. We want to show that the schemes characterized by Proposition 1 are sustainable in the following sense: The supervisors truthfully reveal to which interval the private banks belong, and a private bank in interval I_i is allowed to do net settlement if and only if the foreign bank belongs to an interval smaller or equal to I_{n-i}.

Suppose that the foreign supervisor truthfully reveals the foreign bank's interval. The expected type of a bank in interval I_z is $\frac{1}{2}(q_{n-z-1}^n + q_{n-z}^n)$. Consider $q \in I_i$. From Proposition 1 we have

$$\Delta W^i \left(q_i^n, \frac{1}{2} \left(q_{n-i-1}^n + q_{n-i}^n \right) \right) = 0.$$

As q_i^n is the upper limit of I_i, all banks in I_i are allowed to settle net with a foreign bank in I_{n-i}. It follows immediately that the private bank is also allowed to do net settlement if the foreign bank belongs to an interval lower than I_{n-i}. Consider instead q_{i-1}^n; the lower limit of I_i. Since

$$\Delta W^i \left(q_{i-1}^n, \frac{1}{2} \left(q_{n-i}^n + q_{n-i+1}^n \right) \right) = 0,$$

it follows that a private bank in I_i is not allowed to do net settlement with a foreign bank in I_{n-i+1} (or a higher interval).

We see that a local bank in I_i is allowed by the supervisor to net transfers out with the foreign bank if and only the if foreign bank belongs to an interval in $\{I_1, ..., I_{n-i}\}$; i.e. for all $q_j \leq q_{n-i}^n$.

It is left to show that the supervisors reveal truthfully the interval to which the local bank belongs. If the local supervisor signals truthfully that the local bank is in I_i, it can do net settlement with all foreign banks in $\{I_1, ..., I_{n-i}\}$. It could instead signal that the private bank belongs to I_z, $z < i$. The foreign supervisor would allow net settlement if the foreign private banks belonged to $\{I_1, ..., I_{n-z}\}$. However, as the local supervisor does not allow net settlement if the foreign bank belongs to $\{I_{n-i+1}, ..., I_{n-z}\}$, truthful revelation gives the same expected welfare as signalling a lower interval. Consider instead a deviation to I_y, $y > i$. The foreign supervisor then allows net settlement for all $\{I_1, ..., I_{n-y}\}$. Here truthful revelation dominates signalling I_y as the local supervisor prefers net settlement if the foreign private banks belongs to $\{I_{n-y+1}, ..., I_{n-i}\}$. The supervisors thus reveal truthfully the interval to which the local bank belongs. $\square$

A.3. Proposition 2 and Lemma 2

A.3.1. Existence and Uniqueness of the Scheme with 2 Intervals

From Proposition 1 it follows that q_1^2 is given as the solution to $\Delta W^i\left(q, \frac{1}{2}q\right) = 0$. This implies that

$$-\frac{1}{2}(R-L)q^2 + \left(\frac{1}{2}R + (R-1)L\right)q - (R-1)L = 0 \tag{A.6}$$

It can be shown that there is only one relevant solution to this equation and that $q_1^2 \in (0,1)$. Solving (2.1) gives:

$$q_1^2 = \frac{\frac{1}{2}R + (R-1)L - \sqrt{\left(\frac{1}{2}R + (R-1)L\right)^2 - 2(R-L)(R-1)L}}{R-L}. \tag{A.7}$$

Note that this result does not depend on Assumption 3.

A.3.2. Existence and Uniqueness of the Scheme with 3 Intervals or more

Step 1: *Show that* $q_1^n \leq q_1^2 \leq q_{n-1}^n$.

Since $\Delta W(q_i, q_j) = 0$ is downward sloping, for $\Delta W(x_1, y_1) = 0$ and $\Delta W(x_2, y_2) = 0$, we have $x_1 < x_2 \Longleftrightarrow y_1 > y_2$.

From the incentive constraints, we know that if Φ^2 and Φ^n exist, then we have

$$\begin{aligned} \Delta W(q_1^2, \frac{1}{2}q_1^2) &= 0 \\ \Delta W(q_{n-1}^n, \frac{1}{2}q_1^n) &= 0 \end{aligned} \tag{A.8}$$

Suppose now $q^n_{n-1} < q^2_1$. It follows from (A.8) that $q^n_1 > q^2_1$. But this is a contradiction since $q^n_1 < q^n_{n-1}$. Thus, $q^2_1 \leq q^n_{n-1}$. Using a similar argument, it follows that $q^n_1 \leq q^2_1$.

Step 2: *Inductive definition of sets.*

Consider a scheme with n intervals and assume that n is even. The sets are defined in an analogous way for n uneven. From step 1, we know that $q^2_1 \leq q^n_{n-1} \leq \overline{q}$. Define by S_1 the set of all q^n_{n-1} for which this is true,

$$S_1 = \{q^n_{n-1} : q^2_1 \leq q^n_{n-1} \leq \overline{q}\}.$$

Note that this set is identical for all n.

Now regard the <u>first</u> of the incentive constraints, $\Delta W(q^n_{n-1}, \frac{1}{2}q^n_1) = 0$. Using this equation, we can characterize the set of all possible (q^n_1, q^n_{n-1}), which we denote S_2. Two conditions need to be fulfilled for q^n_1 to form part of a n-interval scheme: Firstly, q^n_1 needs to fulfill the first incentive constraint for a $q^n_{n-1} \in S_1$. Secondly, q^n_1 needs to satisfy $0 \leq q^n_1 \leq q^2_1$ (see step 1). We can then define S_2 as:

$$S_2 = \left\{ (q^n_1, q^n_{n-1}) : 0 \leq q^n_1 \leq q^2_1 \text{ and } \Delta W(q^n_{n-1}, \frac{1}{2}q^n_1) = 0 \text{ and } q^n_{n-1} \in S_1 \right\}.$$

Next, regard the <u>last</u> of the incentive constraints, $\Delta W(q^n_1, \frac{1}{2}(q^n_{n-1} + q^n_{n-2})) = 0$. This equation implicitly defines q^n_{n-2} as a function of q^n_1 and q^n_{n-1}. Similarly to above, we can now define as S_3 the set of all possible $(q^n_1, q^n_{n-2}, q^n_{n-1})$ which fulfill this last incentive constraint for all admissible q^n_1 and q^n_{n-1}, and who are in the relevant range, i.e. fulfill $q^n_1 \leq q^n_{n-2} \leq q^n_{n-1}$. This set is given by:

$$S_3 = \left\{ \begin{array}{c} (q^n_1, q^n_{n-2}, q^n_{n-1}) : q^n_1 \leq q^n_{n-2} \leq q^n_{n-1} \text{ and } \Delta W(q^n_1, \frac{1}{2}(q^n_{n-1} + q^n_{n-2})) = 0 \\ \text{and } (q^n_1, q^n_{n-1}) \in S_2 \end{array} \right\}.$$

In a similar fashion, we can now proceed using the second constraint to obtain a set that includes q^n_2 (denoted S_4), the second-last constraint to obtain a set that includes q^n_{n-3} (denoted S_5), etc., until we have covered all but the last constraint:

$$\begin{aligned} S_4 &= \left\{ \begin{array}{c} (q^n_1, q^n_2, q^n_{n-2}, q^n_{n-1}) : q^n_1 \leq q^n_2 \leq q^n_{n-2} \text{ and } \Delta W(q^n_{n-2}, \frac{1}{2}(q^n_1 + q^n_2)) = 0 \\ \text{and } (q^n_1, q^n_{n-2}, q^n_{n-1}) \in S_3 \end{array} \right\} \\ &\vdots \end{aligned}$$

$$S_{n-1} = \left\{ \begin{array}{c} (q_1^n, .., q_{n-1}^n) : q_{n/2-1}^n \leq q_{n-n/2}^n \leq q_{n-n/2+1}^n \\ \text{and } \Delta W(q_{n/2-1}^n, \frac{1}{2}(q_{n-n/2}^n + q_{n-n/2+1}^n)) = 0 \\ \text{and } (q_1^n, ..., q_{n/2-1}^n, q_{n-n/2+1}^n, ..., q_{n-1}^n) \in S_{n-2} \end{array} \right\}.$$

S_{n-1} is of the same dimension as a solution to the scheme, but it does not take the last constraint into account. We define the set S_n the same way as before. This, however, implies that the elements in S_n are of one dimension higher than the solution. In particular, the elements in S_n have two entries $q_{n-n/2}$ (defined in S_{n-1}) and $q_{n/2}^n$ (defined in S_n) referring to the same variable.

$$S_n = \left\{ \begin{array}{c} (q_1^n, .., q_{n/2-1}, q_{n/2}^n, q_{n-n/2}, .., q_{n-1}^n) : q_{n/2-1}^n \leq q_{n/2}^n \leq q_{n-n/2}^n \\ \text{and } \Delta W(q_{n-n/2}^n, \frac{1}{2}(q_{n/2-1}^n + q_{n/2}^n)) = 0 \\ \text{and } (q_1^n, ..q_{n/2-1}, q_{n-n/2}, ., q_{n-1}^n) \in S_{n-1} \end{array} \right.$$

Step 3: *Conditions for existence of a scheme with n intervals.*

The elements in S_n contain two entries corresponding to the variable $q_{n/2}$ ($\widetilde{q}_{n/2}^n$ and $q_{n-n/2}$). Hence, there exist a scheme with n intervals if and only if there exists an element in S_n satisfying $q_{n/2}^n = q_{n-n/2}$ and $0 < q_1^n < ... < q_{n-1}^n < 1$. Notice that the set S_i is identical for all schemes with i intervals or more, because the constraints defining the sets are the same. If $S_i = \emptyset$, it implies that there cannot exist a scheme with i intervals. However, it also implies that there cannot exist schemes with more than i intervals, as all sets derived inductively from S_i are empty.

Step 4: $\frac{\partial q_{n-2}^n}{\partial q_{n-1}^n} \leq 0$ *(> 0) if Assumption 3 holds (does not hold).*

Under Assumption 3, the supervisors will not allow net settlement if they receive no additional information about the foreign bank's type. If the supervisors receive no information, the expected type of the foreign bank is $\frac{1}{2}$. Under Assumption 3, it must hold that $\Delta W^i(q, \frac{1}{2}) \leq 0$ for all $q \in [0, 1]$. This condition is satisfied if and only if $2(R-1)L/R \leq 1$.

We will need an additional bit of notation. From the definitions of the sets, it can be seen that all the variables can be written as a function of q_{n-1}^n. We thus denote $q_i^n(q_{n-1}^n)$ the value of q_i^n as a function of q_{n-1}^n. Using $\Delta W(q_{n-1}^n, \frac{1}{2}q_1^n) = 0$ and

$\Delta W(q_1^n, \frac{1}{2}(q_{n-1}^n + q_{n-2}^n)) = 0$, we have:

$$q_{n-2}^n(q_{n-1}^n) = \frac{2(R-1)L(1-q_1^n)}{q_1^n L + (1-q_1^n)R} - q_{n-1}^n \text{ where } q_1^n = \frac{2(R-1)L(1-q_{n-1}^n)}{q_{n-1}^n L + (1-q_{n-1}^n)R}.$$

Taking the derivative with respect to q_{n-1}^n yields:

$$\frac{\partial q_{n-2}^n}{\partial q_{n-1}^n} = \frac{4(R-1)^2 L^4}{(q_{n-1}^n L + (1-q_{n-1}^n)R)^2 (q_1^n L + (1-q_1^n)R)^2} - 1.$$

From this follows that $\frac{\partial q_{n-2}^n}{\partial q_{n-1}^n} \leq 0$ implies that

$$\frac{2(R-1)L^2}{q_1^n L + (1-q_1^n)R} \leq q_{n-1}^n L + (1-q_{n-1}^n)R.$$

Using the expression $q_1^n = 2(R-1)L(1-q_{n-1}^n)/(q_{n-1}^n L + (1-q_{n-1}^n)R)$, this reduces to

$$q_1^n \leq \frac{R(1-q_{n-1}^n)}{q_{n-1}^n L + (1-q_{n-1}^n)R}.$$

It is easy to verify that this condition is satisfied if and only if Assumption 3 holds.

Step 5: *Under Assumption 3 there exists no scheme with three intervals or more.*

Before studying S_3, let us determine S_2. It is easy to verify that all values of q_{n-1}^n in S_1 also are a part of S_2. $q_1^n(\cdot)$ is strictly decreasing and continuous in q_{n-1}^n and takes on the values between $q_{n-1}^n(q_1^2) = q_1^2$ and $q_1^n(1) = 0$.

Let us now turn to S_3. Suppose first that $2(R-1)L/R < 1$. For $q_{n-1}^n = q_1^2$, the lowest value of q_{n-1}^nin S_2, we have $q_1^n(q_1^2) = q_1^2$. This implies that $q_{n-2}^n(q_1^2) = 0$. It follows that $(q_1^n, q_{n-2}^n, q_{n-1}^n) = (q_1^2, 0, q_1^2) \notin S_3$ as $q_1^n(q_1^2) > q_{n-2}^n(q_1^2)$. For $q_{n-1}^n > q_1^2$, $q_{n-2}^n(q_1^2) < 0$, as $\frac{\partial q_{n-2}^n}{\partial q_{n-1}^n} < 0$. This violates $0 \leq q_1^n \leq q_{n-2}^n$, so $S_3 = \emptyset$. Since S_3 is empty, there cannot exist schemes with three intervals or more. Next, consider $2(R-1)L/R = 1$. Here, S_3 consists of the element $(q_1^n, q_{n-2}^n, q_{n-1}^n) = (0, 0, 1)$. For $n = 3$, there exist no solution, since the condition $q_1^3 > 0$ is not satisfied. There also exist no schemes with more than n intervals, as the condition $q_{n-2}^n > q_1^n$ is violated.

Step 6: *If Assumption 3 does not hold, there exists a unique scheme with three intervals.*

(Proof of Lemma 2) As in step 5, we study S_3. We have $q_1^n(q_1^2) = q_1^2 > q_{n-2}^n(q_1^2) = 0$. For $q_{n-1}^n = 1$, the highest value of q_{n-1}^n in S_2, we have $q_1^n(1) = 0 < q_{n-2}^n(1) = \frac{2(R-1)L}{R} - 1$. In S_2, q_{n-1}^n takes on all values between q_1^2 and 1. $q_1^n(\cdot)$ and $q_{n-2}^n(\cdot)$

are continuous in q^n_{n-1}. Therefore, since $q^n_1(\cdot)$ and $q^n_{n-2}(\cdot)$ are strictly decreasing and increasing in q^n_{n-1}, respectively, there exists a unique q^n_{n-1}, $\overline{q}^n_{n-1}$, belonging to $(q^2_1, 1)$ such that $0 < q^n_1(\overline{q}^n_{n-1}) = q^n_{n-2}(\overline{q}^n_{n-1}) < \overline{q}^n_{n-1} < 1$. We conclude that there exists a unique scheme with three intervals.□

A.4. Lemma 1 and Proposition 3

We need to show that the two-interval scheme leads to a higher expected welfare than would always choosing gross or net settlement. If the supervisors implement the scheme with two intervals, they can always obtain a gross settlement system by signalling $q_i = 1$. In equilibrium, however, the supervisors signal the banks' true types. It follows from a revealed preference argument that the scheme with two intervals gives higher expected welfare than always implementing a gross settlement system.

Next, we show the scheme with two intervals also dominates a net settlement system for all (q_i, q_j). Let $\widetilde{q}$ be the end point of the first interval in a two interval scheme; that is, the banks settle net iff. $q_1, q_2 \leq \widetilde{q}$. The expected welfare as a function of $\widetilde{q}$ is given as

$$E(W) = \int_0^{\widetilde{q}} \int_0^{\widetilde{q}} W_N dq_2 dq_1 + \int_0^{\widetilde{q}} \int_{\widetilde{q}}^1 W_G dq_2 dq_1 + \int_{\widetilde{q}}^1 \int_0^1 W_G dq_2 dq_1.$$

where the interest rate is given by (B.1) with $\widetilde{q} = q^{PR}$. Integration and maximization yields the first-order condition:

$$\widetilde{q}^2 R(1 - \frac{L}{2}) - \frac{3}{2}\widetilde{q}(RL + R - L) + 2L(R-1) = 0$$

Let $\widetilde{q}^*$ be the solution to the first order condition. Analysis of the first order derivative shows that welfare increases up to $\widetilde{q} = \widetilde{q}^*$, and decreases afterwards. Calculations show that $q^2_1 > \widetilde{q}^*$ and Proposition 3 follows. Furthermore, net settlement for all (q_1, q_2) gives a lower expected welfare than the scheme with two intervals as $1 > q^2_1 > \widetilde{q}^*$ and Lemma 1 follows. □

A.5. Proposition 4

In the regulatory game the private banks move first and propose the mode of settlement. We saw in section 4 that the supervisors allow net settlement if and only if both banks are of a type lower or equal to q_1^2. For this to be the equilibrium outcome, however, the private banks must propose net settlement if they are both of a type lower than q_1^2.

The private banks can exchange information, which is modeled similarly to the regulators' exchange described in section 4.2.1. The private banks agree at time $T = -1$ on a scheme that maps the signals sent by the two banks into a proposal made to the supervisors. We only consider schemes where both banks either propose net or gross settlement, as it is irrelevant whether one or two of the banks propose gross settlement. Denote the scheme by $\Phi^{PR}(\cdot)$. We restrict attention to incentive compatible and piece-wise continuous schemes where the banks propose net settlement if and only if $q_j \leq \Phi^{PR}(q_i)$. Finally, $\Phi^{PR}(\cdot)$ must be symmetric as defined in the proof of Proposition 1.

First, trivial schemes in which banks agree to always settle in a net or always in a gross system exist. Next, let us consider schemes where the proposal made depends on the signals sent. Similar to the information exchange of the regulators, we find that any incentive compatible scheme $\Phi^{PR}(\cdot)$ is a step function. The proof is analogous to step 2 in the proof of Proposition 1.

Consider q_i' and q_i'', $q_i' \neq q_i''$, for which $\Phi^{PR}(q_i') \neq \Phi^{PR}(q_i'')$. For q_i', incentive compatibility requires

$$\Phi' \pi_N^i \left(q_i', \frac{\Phi'}{2} \right) + \left(1 - \Phi'\right) \pi_G^i(q_i') \geq \Phi'' \pi_N^i \left(q_i', \frac{\Phi''}{2} \right) + \left(1 - \Phi''\right) \pi_G^i(q_i') \tag{A.9}$$

where $\Phi' \equiv \Phi^{PR}(q_i')$ and $\Phi'' \equiv \Phi^{PR}(q_i'')$. For q_i'', the reverse inequality needs to hold.

Since the banks' preferences are independent of their type, both constraints have to be fulfilled simultaneously for any $q_i \in [0, 1]$. Therefore, (A.9) has to hold with equality. Defining $\Delta\pi^i(q_i, q_j) \equiv \pi_N^i(q_i, q_j) - \pi_G^i(q_i)$, we find that for any q_i, the constraint reduces to $\Phi' \Delta\pi^i(q_i, \frac{1}{2}\Phi') = \Phi'' \Delta\pi^i(q_i, \frac{1}{2}\Phi(q_i''))$. Rewriting yields

$$\frac{1}{2} \left(\Phi(q_i') + \Phi(q_i'') \right) = q^{PR} \tag{A.10}$$

with q^{PR} defined by (5.1). Symmetry and equation (A.10) imply that there can be only one jump; i.e. the scheme consists of maximally two intervals.

The private banks take into account the public regulation when they exchange information. Let $\widetilde{q}_1^2$ denote the endpoint of the first interval in the public two interval scheme. (Since there cannot exist schemes with more than two intervals if the private propose net settlement for all types, see Lemma 1, these schemes do also not exist if the private banks propose net settlement only for a subset of types.) The supervisors only allow net settlement if both banks are of a type lower or equal to $\widetilde{q}_1^2$. The proposal made for types higher than $\widetilde{q}_1^2$ is thus irrelevant.

Denote the private threshold $\widetilde{q}^{PR}$. Because there can be only one jump, there are only two possible schemes that the private banks can agree upon. The first candidate scheme has the following shape ('L-shaped'):

$$\Phi^{PR}(q_i) = \begin{cases} \widetilde{q}_1^2 & \text{for } q_i \leq \widetilde{q}^{PR} \\ \widetilde{q}^{PR} & \text{for } \widetilde{q}^{PR} < q_i \leq \widetilde{q}_1^2 \\ 0 & \text{for } q_i > \widetilde{q}_1^2 \end{cases}.$$

(A.10) implies that

$$\widetilde{q}^{PR} = 2q^{PR} - \widetilde{q}_1^2 \tag{A.11}$$

where q^{PR} is given by (5.1). It follows that a necessary condition for the scheme to exist is $\widetilde{q}_1^2 < 2q^{PR}$. Consider now the public scheme. Suppose that the local bank is of the type $\widetilde{q}_1^2$. For the scheme to be incentive compatible, the supervisor has to be indifferent between gross settlement and net settlement with the expected type $\frac{1}{2}\widetilde{q}^{PR}$. The following condition must thus hold:

$$\Delta W^i \left(\widetilde{q}_1^2, \frac{1}{2}\widetilde{q}^{PR} \right) = 0. \tag{A.12}$$

Solving (A.11) and (A.12) shows that because of Assumption 3, which implies $(R-1)L/R \leq \frac{1}{2}$, there exist no solution satisfying $\widetilde{q}_1^2 < 2q^{PR}$ The first candidate scheme does thus not exist.

The second candidate scheme has the following form (a square):

$$\Phi^{PR}(q_i) = \begin{cases} \widetilde{q}^{PR} & \text{for } q_i \leq \widetilde{q}^{PR} \\ 0 & \text{for } q_i > \widetilde{q}^{PR}. \end{cases}.$$

The supervisors do not allow net settlement for $q_i > q_1^2$, where q_1^2 is given by (A.7). The private information exchange is therefore only relevant if $\widetilde{q}^{PR} < q_1^2$. The scheme has to be incentive compatible, which implies that

$$\Delta\pi^i(\widetilde{q}^{PR}, \frac{1}{2}\widetilde{q}^{PR}) = 0 \Leftrightarrow \widetilde{q}^{PR} = 2q^{PR}.$$

However, straightforward calculations show that $q_1^2 < \widetilde{q}^{PR} = 2q^{PR}$. The private banks can thus not affect the outcome of the game by playing the second candidate scheme.

The only thing left to show is that foreseeing the public regulation, the private banks prefer to propose net settlement rather than gross settlement. The expected type of the foreign bank given that net settlement is approved is $\frac{1}{2}q_1^2$. Since $\frac{1}{2}q_1^2 < q^{PR}$, the banks prefer net settlement whenever it is allowed by the supervisor. It is thus optimal always to propose net settlement, and the analysis in section 4 goes through. $\square$

A.6. Proposition 5

We first show that there does not exist a scheme with two intervals as defined by Proposition 1. The private banks propose to settle on a net basis whenever $q_1, q_2 \leq (R-1)L/R$. Using (A.7) it can be shown that $(R-1)L/R < q_1^2$. Therefore, the two interval scheme does not exist. It follows from Proposition 2 that there does not exist schemes with more than two intervals. It is left to show that the supervisors accept the private proposal of a net settlement system. The expected type of the foreign bank given that net settlement has been proposed is $\frac{(R-1)L}{2R}$. Calculations show that $\Delta W^i\left(q_i, \frac{1}{2}\frac{(R-1)L}{R}\right) \geq 0$ for all $q_i \leq \frac{R}{R+L}$. As $q_i \leq \frac{(R-1)L}{R} < \frac{R}{R+L}$, it is optimal to accept the private banks' proposal. $\square$

B. The Interest Rate

In a net settlement system, the customers receive $1+r$ if the local bank does not fail. If is does fail, the payment received by customers depends on whether the foreign bank fails or not. If the foreign bank succeeds, the customers receive the reserves that the bank holds plus ASO, $r+t$. If the foreign bank also fails, the customers are only paid r. In a net settlement system, the consumer in Country i will therefore have the following expected payments on their deposits

$$P_N^{PC}(q_i, q_j) = (1 - q_i)(1 + r) + q_i(1 - q_j)(r + t) + q_i q_j r.$$

Similarly, in a gross settlement system, the customers receive $1+r$ if the bank succeeds, and $t + r$ if it fails. Hence, the expected payments are

$$P_G(q_i, q_j) = (1 - q_i)(1 + r) + q_i(t + r).$$

The customers foresee for which (q_1, q_2) net settlement will be chosen in equilibrium. They also know if partial or full contagion applies. Consider first a private system. The interest rate that ensures the customers exactly zero return on the deposits is then the solution to the following equation:

$$\int_0^{q^{PR}} \int_0^{q^{PR}} P_N(q_i, q_j) dq_j dq_i + \int_0^{q^{PR}} \int_{q^{PR}}^1 P_G(q_i, q_j) dq_j dq_i + \int_{q^{PR}}^1 P_G(q_i, q_j) dq_i = 1$$

Solving for r, we obtain

$$r = \frac{1}{2} - \frac{t}{2}\left(1 - \frac{(q^{PR})^4}{2}\right) \tag{B.1}$$

In a public system with n intervals, the interest rate is given by

$$\sum_{i=0}^{n-1} \int_{\overline{q}_i}^{\overline{q}_{i+1}} \int_0^{\overline{q}_{n-1-1}} P_N(q_i, q_j) dq_j dq_i + \sum_{i=0}^{n-1} \int_{\overline{q}_i}^{\overline{q}_{i+1}} \int_{\overline{q}_{n-1-1}}^1 P_G(q_i, q_j) dq_j dq_i = 1$$

C. Optimal Reserve Holdings

Denote the amount of reserves held $\widetilde{t}$ and the optimal amount of reserves t^*. The profits in the *gross settlement system* are:

$$\pi_G(\widetilde{t}) = \begin{cases} (1 - q_i)\left[(1 - r - \widetilde{t} - \frac{t+r-\widetilde{t}}{L})R - (1 - t)\right] & \text{for } \widetilde{t} < t + r \\ (1 - q_i)\left[(1 - r - \widetilde{t})R - (1 - \widetilde{t})\right] & \text{for } \widetilde{t} \geq t + r \end{cases}.$$

It is easy to verify that profits are increasing in $\widetilde{t}$ for $\widetilde{t} \leq t + r$, as the banks needs $t + r$ reserves to settle payments and to pay Customers A the promised interest rate. Hence, $t^* = t$.

Consider next the *net settlement system.* It can be shown that it is never optimal to hold less reserves than r, as reserves of r are needed to pay Customers A. Suppose therefore that the bank holds $\widetilde{t} \geq r$ reserves. The profits are:

$$\pi_N(\widetilde{t}|\widetilde{t} \geq r) = (1 - q_i)\left\{(1 - q_j)\left[(1 - r - \widetilde{t})R - 1 + \widetilde{t}\right] + q_j\left[(1 - r - \widetilde{t})R - 1 + \widetilde{t} - t\right]\right\}.$$

Taking the derivative with respect to $\widetilde{t}$, we find

$$\frac{\partial \pi_N}{\partial \widetilde{t}} = (1 - q_i) \left[q_j \left(\frac{R}{L} - q \right) - (R - 1) \right].$$

Thus,

$$t^* = \begin{cases} r & \text{if } q_j < \frac{R-1}{\frac{R}{L}-1} = \frac{(R-1)L}{R-L} \\ t + r & \text{else} \end{cases} \tag{C.1}$$

We want show that the private banks choose $t = r$ in the region where a net settlement system is implemented. Suppose first that private banks have perfect information about each others' type. A net settlement system is then implemented if and only if $q_j \leq \frac{(R-1)L}{R} < \frac{(R-1)L}{R-L}$. Hence, the banks choose $t^* = r$.

Now suppose that the private banks have no informational advantage. Before the information exchange, the expected type of the foreign bank given that there is net settlement system is $\frac{1}{2}\Phi^n(q_i)$. The supervisor could obtain gross settlement with certainty by signalling $q_i = 1$. Instead, it could choose to reveal the type truthfully, which implies that $\frac{1}{2}\Phi^n(q_i) \leq \frac{(R-1)L}{R}$. After the information exchange, the supervisor knows the foreign bank's type, but he cannot pass this information on to the local bank. Hence, if net settlement is allowed, the local bank believes the foreign bank is of the expected type $\frac{1}{2}\Phi^n(q_i)$. Since $\frac{1}{2}\Phi^n(q_i) \leq \frac{(R-1)L}{R} < \frac{(R-1)L}{R-L}$, it follows from (C.1) that the optimal reserve holding is $t^* = r$.

Suppose instead that signals are non-binding, such that the supervisor only knows to which interval the foreign bank belongs. If the supervisor allows net settlement with a bank in interval I_z, it must hold that $\frac{1}{2}(q_{z-1}^n + q_z^n) \leq \frac{(R-1)L}{R}$. It follows that the private bank chooses $t^* = r$ whether it knows that the foreign bank is in I_z or it just knows that net settlement was approved by the supervisor. Hence, if signals are non-binding, it does not change the portfolio choice if the supervisor leaks the information he has about the foreign bank's type to the local bank.

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