Regulating Access to International Large-Value Payment Systems

Cornelia Holthausen
European Central Bank

Thomas Rønde
University of Mannheim

This article studies access regulation to international large-value payment systems when banking supervision is national. We focus on the choice between net and real-time gross settlement. As a novel feature, the communication between the public authorities is endogenized. It is shown that the national authorities' incentives are not perfectly aligned concerning the settlement method. Therefore public regulation fails to implement the first-best access criteria. Banks prefer net settlement too often due to limited liability. Still, if banks have superior information about their counterparties, private involvement in access regulation is desirable as it reveals information to the public authorities.

The last decades have witnessed a substantial increase in the volume of transactions that are processed via large-value payment systems. In the United States, for example, the combined payment value processed in the Clearing House Interbank Payment System (CHIPS) and Fedwire exceeded US$2.5 trillion per day in 1999. 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 can 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

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[1] Statistics concerning the transfers in Fedwire and CHIPS can be found on the Web page of the Federal Reserve Bank of New York at www.ny.frb.org/pihome/fedpoint.

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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, usually operating in real time, and netting systems. In real-time gross settlement systems (RTGSs), 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 prespecified 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, this 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 an important concern, a RTGS is the better 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.

RTGSs and net settlement systems frequently coexist. In the European Union (EU), for example, the central banks of the EU countries have introduced TARGET, a cross-border RTGS. 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 United States, the Federal Reserve Banks operate Fedwire, which offers RTGSs, while CHIPS is a privately run net settlement system.

In this article we study access regulation to coexisting net settlement and RTGSs 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 when 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 was the European cross-border settlement

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

systems. However, the issues that we study here also arise in domestic payment 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 customers 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: first, they are able to invest in profitable, long-run technologies, which short-lived customers can not do. Second, banks are participating in an international payment system, enabling their customers to make transfers abroad. Banking supervision is the task of a local supervisor, who maximizes his or her own country's welfare. We assume that the local supervisor can observe the risk of the local but not the foreign bank. Concerning the banks' information, we study two different scenarios. In the first, we assume that banks have the same information as the supervisors. It seems plausible that banks operating internationally are better informed about the risk of their foreign counterparts than the local supervisors, so as a second scenario we assume that the 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, access to the net system is regulated. For simplicity, we abstract from explicitly modeling 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 net system.

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. The banks, on the other hand, face limited liability, which induces them to choose net settlement too often. As a result, the welfare-maximizing access regulation cannot be achieved. In spite of the incentive problems, however, the communication between supervisors allows them to regulate more efficiently. In particular, we show that the access regulation results in higher welfare than always imposing either net or gross settlement. Our main policy result is that supervisors should always participate in access regulation. However, if the banks have superior information about each other's riskiness, it is crucial that they are also actively involved in the regulation, as this reveals valuable information to the supervisors.

The theoretical literature on large-value payment systems has mainly focused on the choice between net and gross settlement. Freixas and Parigi (1998) analyze the trade-off between the risk of contagion in a net settlement

[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. In our simplified setup with only two national agencies, we are nevertheless able to capture the problem of conflicting interests and the need to coordinate information from different sources.

system and the higher liquidity needs in a RTGS. Kahn and Roberds (1998) argue that in a net system, participants might have incentives to default on their outstanding payments. The coexistence of both types of systems is discussed in Rochet and Tirole (1996). Other authors [e.g., Giovannini (1992) and Schoenmaker (1995)] have studied problems concerning the international division of banking supervisory powers. To our knowledge, this is the first article 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 authorities. In the modeling of the communication, we draw on previous work by, in particular, Crawford and Sobel (1982) and Melumad and Shibano (1991).

The article is organized as follows. In Section 1, the model is described. Section 2 discusses the effects of gross and net settlement on the banks' portfolio choice and on systemic stability. In Section 3 we analyze the access conditions to the net system imposed by the public regulators. This is done first under the assumption that each regulator can observe both banks' types, and then assuming local supervision. The banks' preferences regarding the mode of settlement as well as the interaction between private and public regulation are derived in Section 4. Section 5 concludes. Most proofs are in the appendix.

1. The Model

1.1 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 two 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 B deposit and customers A withdraw their money. The bank can thus use the newly deposited funds to pay parts of its obligation to customers A. All customers demand a nonnegative 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 $\tilde{q}_i$. In order to have asymmetric information about the riskiness of the local bank, we assume that $\tilde{q}_i$ is a random variable. $f(\cdot)$ denotes the density function of $\tilde{q}_i$, and $F(\cdot)$ is the corresponding distribution function. $f(\cdot)$ takes positive values on the interval $[0, 1]$. For simplicity, for most parts of the article it is assumed that $\tilde{q}_i$ is uniformly distributed on $[0, 1]$. The realization of $\tilde{q}_i$ 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.

1.2 Payment systems

A customer in country i can make payments to a customer in country j by transferring funds from his or her 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 in which 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. As long as there is no failure, net liabilities are zero, so 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; that is, 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 banks agree upon it.

1.3 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] Furthermore, we 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 that (1) a failure of a bank's risky

[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 nonbalanced payment streams such that a failing bank could have net liabilities.

technology leads to bankruptcy of this bank, and (2) in the netting system, the other bank (if not bankrupt) is obliged to transfer t to the failing bank, which the receiving bank then will use to repay 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.

1.4 Supervision and regulation

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

The local supervisors decide jointly about banks' use of the net system. Only if both supervisors agree are the banks allowed to settle on a net basis. Otherwise they have to use the gross settlement system. The supervisors regulate access to maximize local welfare. Welfare-maximizing access regulation, however, depends on the risk of both the local and the foreign bank, that is, on the information gathered by both supervisors. Therefore the supervisors have incentives to exchange information about the banks' risk.

We model the information exchange in the following way: Before the banks' types are realized, the supervisors agree upon a scheme that decides for which (q_1, q_2) net settlement should be allowed. Throughout the article we denote these schemes by $\Phi^k(\cdot)$. We will consider different schemes, so k indicates the type of scheme. $\Phi^k(\cdot)$ gives the maximal riskiness of the foreign bank for which net settlement is allowed as a function of the local bank's type. We focus on schemes that treat the countries symmetrically, that is, schemes such that $\Phi^k(\cdot) = (\Phi^k)^{-1}(\cdot)$. Because the countries are ex ante identical, symmetry implies that there is no conflict of interest when the scheme is negotiated. Therefore the supervisors agree on the scheme that maximizes expected welfare.

After the scheme has been chosen, the regulatory game is as follows: (1) the banks can apply to settle on a net basis, and (2) the supervisors report the local banks' type to each other. If the types are such that netting should be allowed according to the prenegotiated scheme, the permission is granted. Otherwise the banks use the gross system. The information received from the foreign supervisor is confidential and supervisors do not pass this information on to the banks.

We assume that there is no deposit insurance, as we are considering large-value payment systems. The transfers in these systems usually originate from corporate clients rather than single households and are very large on average.

Table 1
The timing of the game

	$T=0$	$T=1$	$T=2$
Morning		Customers A transfer Gross system: settlement	Customers B transfer Gross system: settlement
Evening	Customers A deposit Supervisors (and banks) agree on scheme Bank and supervisor i observe q_i Banks apply to use net system Information exchange Supervisors decide upon access Banks invest	Risky returns observed Customers B deposit Net system: settlement Customers A withdraw	Risky returns realized Net system: settlement Customers B withdraw

Deposit insurance, as it is in place in most countries, would therefore only cover a small fraction of the deposits in question.[5,6]

1.5 Information

At time 0, the local bank and the local supervisor can observe the local bank's type. We consider both the situation where the banks observe each other's type and where they do not. At time 1, all agents receive a perfect signal about the success of the risky project in both countries. Furthermore, we assume that customers observe the type of settlement system used only at time 1, that is, only at the time when the signal about the return of the risky asset is received. Our main results do not depend on this assumption, but it allows us to solve the model in closed form.[7] Table 1 illustrates the timing.

2. Gross and Net Settlement

2.1 The customers

At time 0, when the deposit contract with customers A is signed, neither the banks' types nor the settlement system are known. However, the risk incurred by customers A when depositing in the bank depends on both these factors. Customers A therefore demand an interest rate, r, which compensates them for this risk. In the following analysis, we will see that the interest rate does not affect the choice of settlement system. This allows us to solve the game without deriving the equilibrium interest rate explicitly.

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, customers B are

[5] In the Euro area, for example, deposit insurance covers between 15,000 and 100,000 Euros [see Masciandaro and Cappella (1999)]. However, the average size of cross-border payments for commercial use in TARGET is more than 1,300,000 Euros (source: ECB Monthly Bulletin, November 1999).

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

[7] Suppose 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 consumers withdrawing their deposits. For an analysis of the model with contingent interest rates, see Holthausen and Rønde (2000).

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. They 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 customers B invest in a bank with a successful technology. For now, notice that customers B face no uncertainty about the value of the bank's assets. Hence, *if* customers B deposit, they demand zero interest rate, as they are certain to be repaid.

2.2 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. Since customers B deposit only 1, but the banks have to pay $1+r$ to customers A, the banks hold additional r reserves on top of the settlement requirements in the first period. At time 0, banks must invest at least $t+r$ into reserves. For now, assume that the remaining $1-t-r$ are invested into the risky technology.[8]

If customers B deposit, customers A withdraw $1+r$ at time 1. Each bank then holds 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

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

We assume that Equation (1) holds.[9] If the risky technology is unsuccessful, customers B do not deposit. The bank is then forced into bankruptcy at time 1, because it cannot pay $1+r$ to customers A. Since the liquidation value of an unsuccessful technology is zero, 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

$$\pi_G^i(q_i) = (1-q_i)[(1-r-t)R-(1-t)] \tag{2}$$

and expected welfare is

$$W_G^i(q_i) = (1-t-r)[(1-q_i)R-1]. \tag{3}$$

Welfare and profits do not coincide because of limited liability and because the customers face informational constraints. The bank does not take into

[8] It can be shown that this is the profit-maximizing portfolio choice in equilibrium. Details are available upon request.

[9] If Equation (1) does not hold, the banks cannot invest in the risky technology under gross settlement. Welfare and profits are then trivially equal to zero.

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 rate reflecting the true risk incurred when depositing in the bank. The interest rate would make the banks 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 a wedge between public and private interests.[10]

2.3 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 customers A the promised interest rate. We assume that the remainder $1-r$ is invested in the risky technology. As before, it can be shown that this is optimal in equilibrium.

Suppose that the risky technology of one of the banks fails. The bank with the low return goes bankrupt because customers B do not deposit. However, the profits of the other bank are adversely affected as well because of the ASO. Following our assumptions, the ASO is equal to t. The bank holds only r reserves, which it has to pay to customers A at time 1. To pay (parts of) the ASO, it is necessary to liquidate $\min\{1-r, \frac{t}{L}\}$ of the risky technology. In the analysis we focus on the case where the bank can repay customers B even after liquidating some of the risky technology. Customers B will thus deposit, and the bank survives. This occurs if and only if[11]

$$\left(1-r-\frac{t}{L}\right)R \geq 1. \tag{4}$$

If Equation (4) did not hold, the bank could not repay customers B, these would not deposit, and all of the risky technology would be liquidated to pay customers A. This case will be briefly discussed in the conclusion.

Under Equation (4), a bank will make positive profits if its own risky technology is successful. 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

$$\pi_N^i(q_i, q_j) = (1-q_i)[(1-r)R-1] - (1-q_i)q_j t\frac{R}{L}. \tag{5}$$

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 in the netting system because there is a high probability that the bank has to pay the ASO, t.

[10] Welfare and profits would still not coincide if the customers observed the settlement system but not the types of the banks.

[11] Note that Equation (4) also implies that customers B deposit in the gross system when the return is high.

The expected welfare of country i is

$$W_N^i(q_i, q_j) = (1-r)[R(1-q_i)-1] - t\left[(1-q_i)q_j\frac{R}{L} - q_i(1-q_j)\right]. \qquad (6)$$

In 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.

3. 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 case where there is local supervision and the supervisors observe only the local bank's type.

As a benchmark, we first determine how access to the net settlement system is regulated if the supervisors can set up an optimal mechanism ("constrained first best"). The optimal mechanism determines, as a function of the types signaled, the mode of settlement as well as a monetary transfer between the countries. We have in mind a situation where the national supervisors are sovereign and not directly subject to any international authority. Therefore it is assumed in the analysis of the full model ("local supervision") that the supervisors can implement a scheme that decides whether net settlement is approved, but it is not possible to use transfers to elicit the supervisors' private information.

In order to present the strategic interaction between the supervisors as clearly as possible, we assume that the 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. Section 4 studies the proposal made by the banks.

3.1 Symmetric information

We analyze the outcome if the supervisors receive a perfect signal about the risk of the local and 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:

$$\begin{aligned}\Delta W^i(q_i, q_j) &\equiv W_N^i(q_i, q_j) - W_G^i(q_i)\\ &= t(R-1)(1-q_i) - q_j t\left(q_i + (1-q_i)\frac{R}{L}\right). \qquad (7)\end{aligned}$$

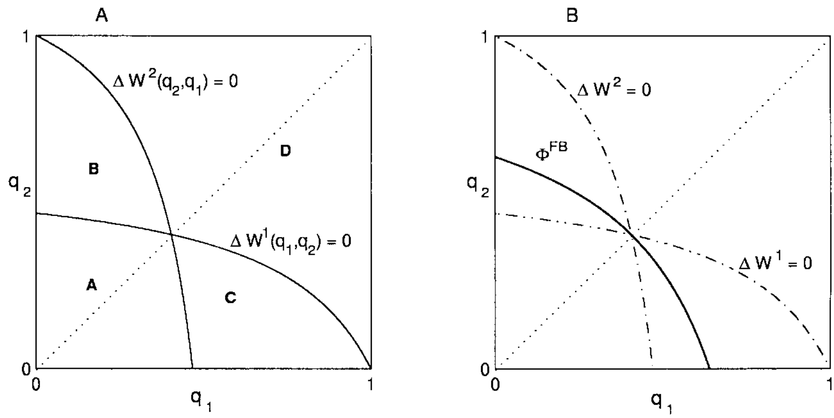

Figure 1
The public preferences

$\Delta W^1(q_1, q_2) = 0$ and $\Delta W^2(q_2, q_1) = 0$ are displayed in Figure 1A. $\Delta W^i(q_i, q_j) = 0$ 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.

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 1A illustrates how the interests of the two countries do not completely coincide. In the regions A and D, both countries prefer net and gross settlement, 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 net settlement. The supervisor in the country with the lower-risk bank is more reluctant to use net settlement, as the bank is relatively more likely to pay ASO than to receive it.

We make one additional assumption:

Assumption 1. *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 possible case. As the ex ante expected type of the banks is $\frac{1}{2}$, Assumption 1 implies that $\Delta W^i(q_i, \frac{1}{2}) \leq 0$ for all q_i. This is equivalent to restricting parameters to $\frac{(R-1)L}{R} \leq \frac{1}{2}$.

3.2 Benchmark: the constrained first best

In this section we assume that there is local supervision. Therefore the supervisors have private information about the local bank's riskiness. For later comparison, we determine how access to the net system is regulated if the supervisors can set up an optimal mechanism. This gives the upper bound on the efficiency of access regulation given the constraints imposed by the supervisors' private information.

We start by deriving the *unconstrained* first-best access regulation. This is characterized by a scheme, $\Phi^{FB}(\cdot)$, which maximizes the expected joint welfare of the two countries. $\Phi^{FB}(\cdot)$ is defined by the following equation:

$$\Delta W^i(q_i, \Phi^{FB}(q_i)) + \Delta W^j(\Phi^{FB}(q_i), q_i) = 0 \text{ for all } q_i \in [0, 1]. \tag{8}$$

$\Phi^{FB}(\cdot)$ is (weakly) decreasing in q_i, as Figure 1B shows, and lies between the $\Delta W^i = 0$ and $\Delta W^j = 0$ curves.

When deriving the *constrained* first-best regulation, the supervisors' incentives are taken into account. Denote the signals that country i and j send about their types by s_i and s_j, respectively, and write the mechanism chosen by the supervisors $\{\Phi(s_i), t_i(s_i), t_j(s_j)\}_{(s_i,s_j)\in[0,1]}$. $t_i(s_i)$ ($t_j(s_j)$) is the transfer from country j to country i (i to j) as a function of s_i (s_j).[12] Net settlement is allowed if $s_j \leq \Phi(s_i)$. Invoking the revelation principle, we restrict attention to incentive-compatible mechanisms.

Consider the situation at time $T = 0$ after the types have been realized. Assuming truth-telling by the foreign supervisor, the expected welfare of country i is a function of q_i and s_i:

$$W^i(q_i, s_i) = \int_0^{\Phi(s_i)} W_N^i(q_i, q_j) f(q_j)\, dq_j + \int_{\Phi(s_i)}^1 W_G^i(q_i) f(q_j)\, dq_j + t_i(s_i) - \int_0^1 t_j(q_j) f(q_j)\, dq_j. \tag{9}$$

We characterize the constrained optimal scheme in the appendix. We use the result from the mechanism design literature that any weakly decreasing (increasing) scheme is implementable if and only if the single crossing condition (−) or (+) is satisfied.[13] The problem is nonstandard, as the preferences

[12] At the time the supervisors signal the banks' type, they consider the expected net transfer, which is independent of the realized type in the other country. Therefore it is without loss of generality to consider transfers that are a function of the local bank's type only.

[13] The single crossing condition (–) (or (+)) holds if $\partial^2 W^i / \partial\Phi\partial q_i < (>) 0$.

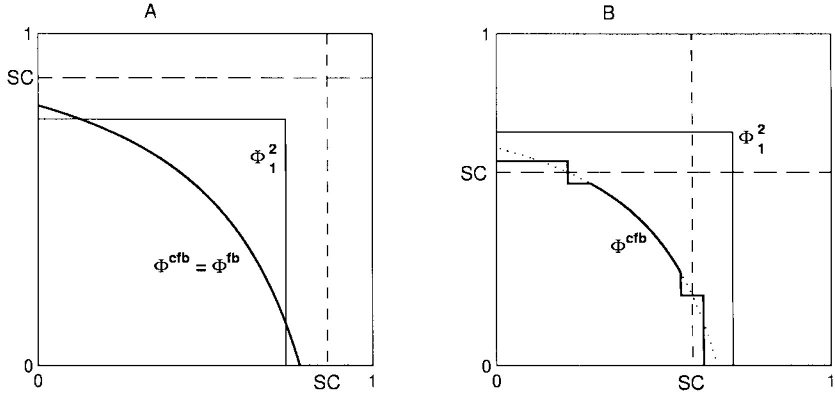

Figure 2
The constrained first-best scheme

of the supervisors are nonmonotonous. In particular, the single crossing condition (+) holds for $\Phi(q_i) > SC$, where $SC \equiv (R-1)L/(R-L)$, while the single crossing condition (−) holds below SC.

We show that there are two cases to consider. In the first case, $R - L \leq RL$, $\Phi^{FB}(q_i)$ is below SC for all q_i. $\Phi^{FB}(\cdot)$ is thus implementable, as it is decreasing. If $R - L > RL$, $\Phi^{FB}(\cdot)$ cannot be implemented because it takes on values greater than SC. Figure 2B illustrates a typical solution in this case. $\Phi^{CFB}(\cdot)$ is constant above SC, since it is not possible to implement a decreasing function in this region. For q_i sufficiently high, where net settlement is less attractive, $\Phi^{CFB}(\cdot)$ jumps below SC and is decreasing thereafter. We treat this case in more detail in the appendix. Proposition 1 summarizes the most important results.

Proposition 1. *The constrained optimal scheme,* $\Phi^{CFB}(\cdot)$, *is characterized as follows*:

(i) *if* $R - L \leq RL$, $\Phi^{CFB}(\cdot) = \Phi^{FB}(\cdot)$,
(ii) *if* $R - L > RL$, $\Phi^{CFB}(\cdot)$ *is weakly decreasing and* $\Phi^{CFB}(0) \leq \Phi^{FB}(0)$.

3.3 Local supervision: the information exchange

We now turn to the full model, where it is not possible to set up a mechanism (or an institution) that uses transfers to extract the supervisors' private information. We model the information exchange in the spirit of "cheap talk": the supervisors can costlessly signal the risk of the banks through written or oral communication. Hence there are neither transfers nor signaling cost to screen the different types. The existing literature analyzing signaling games in such an environment looks at situations with one sender and one receiver [see, e.g., Crawford and Sobel (1982), Stein (1989), and Melumad and Shibano (1991)]. 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 supervisors decide at time 0 for which combinations of types net settlement is allowed. We assume that this agreement can be represented by a piecewise continuous scheme, $\Phi(\cdot)$. Furthermore, as explained above, we restrict attention to symmetric and incentive-compatible schemes. There exist, of course, incentive-compatible schemes where the supervisors agree to always allow or forbid net settlement. In the following, we show how the equilibrium is constructed when the information exchange matters for the choice of settlement system.

Lemma 1. $\Phi(\cdot)$ *cannot be continuously increasing or decreasing on an open set.*

Lemma 1 implies that an incentive-compatible scheme has to consist of constant segments, possibly with "jumps." The supervisors' incentives are somewhat aligned, but not perfectly so. Therefore they have incentives to pretend to be of 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.

The next lemma gives necessary conditions for the scheme to be incentive compatible around the jumps. Denote $E[q_j|I_k] \equiv \int_{q_{k'}^n}^{q_k^n} \frac{q_j f(q_j)}{F(q_k^n)-F(q_{k'}^n)}\,dq_j$, the expected type of the foreign bank given that it belongs to interval $I_k = (\min(q_k, q_{k'}), \max(q_k, q_{k'})]$.

Lemma 2. *Consider two neighboring intervals,* $I_h = (q_{h-1}, q_h]$ *and* $I_{h+1} = (q_h, q_{h+1}]$, $q_{h-1} < q_h < q_{h+1}$, *where* $\Phi(q_i) = q_k$ *for* $q_i \in I_h$ *and* $\Phi(q_i) = q_{k'}$ *for* $q_i \in I_{h+1}$, $q_k \neq q_{k'}$. *Necessary conditions for the scheme to be incentive compatible are*

(i) $\Delta W^i(q_h, E[q_j|I_k]) = 0$
(ii) $q_k > q_{k'}$.

Proof. Incentive compatibility requires that

$$\int_0^{q_k} W_N^i(q_i, q_j) f(q_j)\,dq_j + \int_{q_k}^1 W_G^i(q_i) f(q_j)\,dq_j \underset{(\leq)}{\geq} \int_0^{q_{k'}} W_N^i(q_i, q_j) f(q_j)\,dq_j + \int_{q_{k'}}^1 W_G^i(q_i) f(q_j)\,dq_j$$

$\forall q_i \in (q_{h-1}, q_h]$ ($\forall q_i \in (q_h, q_{h+1}]$). Using Equation (7), these constraints reduce to

$$(F(q_k) - F(q_{k'}))\Delta W^i(q_i, E[q_j|I_k]) \begin{cases} \geq 0 & \forall q_i \in (q_{h-1}, q_h] \\ \leq 0 & \forall q_i \in (q_h, q_{h+1}]. \end{cases} \tag{10}$$

Part (i) of the Lemma 2 then follows from $q_k \neq q_{k'}$ and continuity of ΔW^i.

The expected interim profit can be written in the form of Equation (9) with $t_i(\cdot), t_j(\cdot) = 0$. It follows from part (i) that $E[q_j|I_k] \leq \frac{(R-1)L}{R} < \frac{(R-1)L}{R-L}$. This implies that the single crossing condition (–) is satisfied: $\frac{\partial^2 W^i}{\partial\Phi\partial q_i}|_{\Phi=E[q_j|I_k]} = f(E[q_j|I_k])\frac{\partial\Delta W^i(q_i,E[q_j|I_k])}{\partial q_i} < 0$ for all $q_i \in [0, 1]$. For Equation (10) to be satisfied for all types in I_h and I_{h+1}, it thus has to hold that $q_k > q_{k'}$. ■

Using the two previous lemmata, it is now possible to characterize the incentive-compatible schemes.

Proposition 2. *Suppose the banks' types are distributed between* 0 *and* $\tilde{q}$. *Under local supervision, the supervisors can exchange information using a symmetric, incentive-compatible scheme* $\Phi_z^n(\cdot)$, *which is characterized as follows*:

1. $\Phi_z^n(\cdot)$ *consists of* n *intervals,* $n \geq 2$. *Let interval* h, $1 \leq h \leq n$, *be defined as* $I_h \equiv (q_{h-1}^n, q_h^n]$ *with* $q_{h-1}^n < q_h^n$, $q_0^n = 0$, *and* $q_n^n = \tilde{q}$;
2. *There are two possible types of schemes*: *type* 1 *where* $\Phi_1^n(q_i \in I_h) = q_{n-h}^n$ *and type* 2 *where* $\Phi_2^n(q_i \in I_h) = q_{n-h+1}^n$, $h = 1, \ldots, n$;
3. $\{q_1^n, q_2^n, \ldots, q_{n-1}^n\}$ *are given as the solution to the system of equations*

$$\textit{(type 1)}: \Delta W^i\big(q_h^n, E[q_j|I_{n-h}]\big) = 0, \quad h = 1, \ldots, n-1$$
$$\textit{(type 2)}: \Delta W^i\big(q_h^n, E[q_j|I_{n-h+1}]\big) = 0, \quad h = 1, \ldots, n-1$$

Under schemes in Proposition 2, the supervisors reveal the banks' types truthfully, and the banks settle in the net system whenever $q_j \leq \Phi_z^2(q_i)$. There can exist two types of schemes: type 1 schemes where $\Phi_1^n(q_i \in I_n) = 0$ and type 2 schemes where $\Phi_2^n(q_i \in I_n) > 0$. The schemes of type 1 (2) are constructed such that if the local bank is of type q_i^n, that is, on the border between interval I_i and I_{i+1}, the supervisor is precisely indifferent between letting the bank do net or gross settlement with the average type in interval I_{n-i} (I_{n-i+1}). Together with the single crossing condition, this ensures that the schemes are incentive compatible. Both types of schemes with two intervals are illustrated in Figure 3 for a uniform distribution of types. Indifference on the border between the two intervals implies here that the schemes are symmetric around $\Delta W^i(q_i, q_j) = 0$ at q_1^2.

For most parts of this article, we restrict the analysis to the case of types that are distributed uniformly on the unit interval.

Corollary 1. *Suppose that* q_i *and* q_j *are uniformly distributed on* $[0, 1]$. *Then schemes of type* 2 *cannot exist. A scheme of type* 1 *with* n *intervals,* $\Phi_1^n(\cdot)$, *needs to satisfy* $\Delta W^i(q_h^n, \frac{1}{2}(q_{n-h-1}^n + q_{n-h}^n)) = 0$ *for* $h = 1, \ldots, n-1$.

Proposition 3. *Suppose that* q_i *and* q_j *are uniformly distributed on* $[0, 1]$. *Under Assumption 1 there exists a unique scheme of type* 1 *with two intervals and none with more than two intervals.*

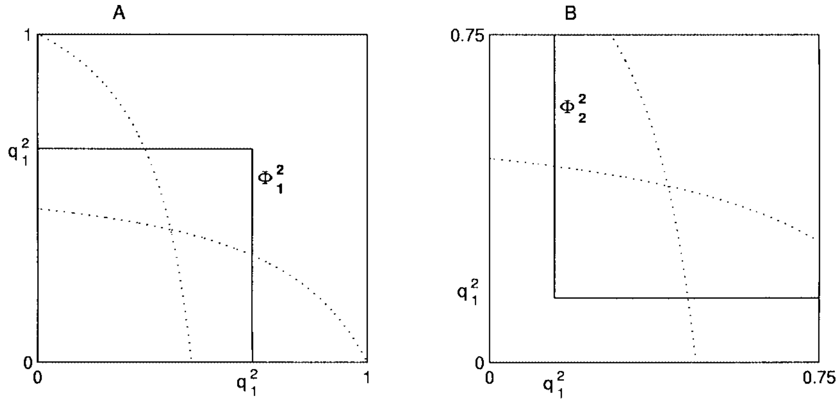

Figure 3
Two-interval schemes for uniform distributions

From Corollary 1 and Proposition 3 it follows that we only need to consider schemes with one interval (i.e., always accept or reject the proposal of net settlement) and $\Phi_1^2(\cdot)$.[14]

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 our results do not depend critically on whether signals are binding or not. If signals were nonbinding, the supervisors would first send the signals. After having received the signal, the supervisors would unilaterally decide whether to accept net settlement. Corollary 2 shows that $\Phi_1^2(\cdot)$ would also be incentive compatible with nonbinding signals.[15] The only difference is that instead of reporting the type, the supervisors would report the interval to which the local bank belongs.

Corollary 2. *If the types are uniformly distributed on* $[0, 1]$ *and signals are nonbinding, the supervisors can exchange information using the scheme* $\Phi_1^2(\cdot)$.

3.4 The (in)efficiency of public regulation

The previous section analyzed the communication between the supervisors. It was shown that without transfers there exists only one candidate equilibrium $\Phi_1^2(\cdot)$ where the supervisors exchange information. We first show that even if the information exchange is impaired by the supervisors' conflicting interests, it is still better than no exchange. In the proof it is shown that regulating access according to $\Phi_1^2(\cdot)$ gives a higher expected welfare than deciding on the settlement system before the banks' risk are known.

[14] Even when Assumption 1 is not satisfied, no schemes with more than three intervals can exist. Details are available upon request.

[15] The proof is straightforward, but details are available upon request.

Proposition 4. *The supervisors regulate the access to the net settlement system more efficiently if they exchange information.*

Let us now compare the two-interval scheme with the constrained first-best scheme $\Phi^{CFB}(\cdot)$ derived in Section 3.2. The schemes are illustrated in Figure 2. The first thing to notice is that $\Phi_1^2(\cdot)$ does not coincide with the constrained first best. This is evident in the case $R - L \leq RL$, since there exists an interval for which $\Phi^{CFB}(\cdot)$ is continuously decreasing in the type. It is also true for $R - L > RL$, as it can be shown that $\Phi_1^2(0) > \Phi^{FB}(0) \geq \Phi^{CFB}(q_i)$ for all $q_i \in [0, 1]$. This leads to the following remark:

Remark. The constrained first-best access regulation cannot be achieved without transfers. ■

From the discussion above it follows that if $R - L > RL$, there is too much net settlement under the two-interval scheme. Figure 2B shows how the two-interval scheme lies further out than the constrained first best. Therefore the banks are allowed to do net settlement for types where gross settlement would be optimal. In the other case, $R - L \leq RL$, $\Phi^{FB}(\cdot)$ is implementable. Here, $\Phi^{FB}(0) > \Phi_1^2(0)$. This implies, as shown in Figure 2A, that there is too little net settlement if one of the banks is of low risk type, but too much if both banks are of intermediate types. For this reason, it is not possible to say unambiguously that access regulation is too lax.[16]

It is important to notice that the surplus of the customers is not affected by the relative efficiency of regulation. The customers foresee the equilibrium outcome and ask for an interest rate that compensates them for the risks they incur. The cost of inefficient access regulation is thus carried by the banks.

4. The Banks' Proposal

We turn now to the settlement decision of the banks. In the previous section, it was assumed that the 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 banks' wishes. It is thus left to be shown that the banks propose net settlement in the region where the supervisors allow it. The banks' proposal depends both on the regulation they foresee and on the information they have about each other.

The analysis of the banks' proposal has three parts. First, we determine the banks' preferences over net and gross settlement. Afterwards we solve the model assuming that they have no more information than the supervisors. We show that the results derived under public regulation are an equilibrium outcome. It seems plausible, however, that a bank operating internationally

[16] It is possible to show, however, that there is more net settlement than there would be under symmetric information.

can have better information about its foreign counterparts than the national supervisor. Ideally the regulation of the payment system should be designed to take advantage of the private agents' information. In the last part, we study how the regulator can use the information revealed by the private proposal to regulate efficiently.

4.1 Gross and net settlement

Let us start by determining the banks' preferences over the mode of settlement. From Equations (2) and (5), we derive a threshold, q^{PR}, for the foreign bank's risk such that bank i is indifferent between gross and net settlement:

$$q^{PR} \equiv \frac{R-1}{R} L \tag{11}$$

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. It is important to notice that a 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 the point of view of welfare, the bank chooses net settlement too often unless it is sure not to fail. Figure 4A illustrates this point: q^{PR} is above $\Delta W^i = 0$, except for $q_i = 0$ where they coincide.

4.2 No informational advantage

Suppose that neither the local bank nor the supervisor observes the risk of the foreign bank. We assume that the banks can exchange information in a

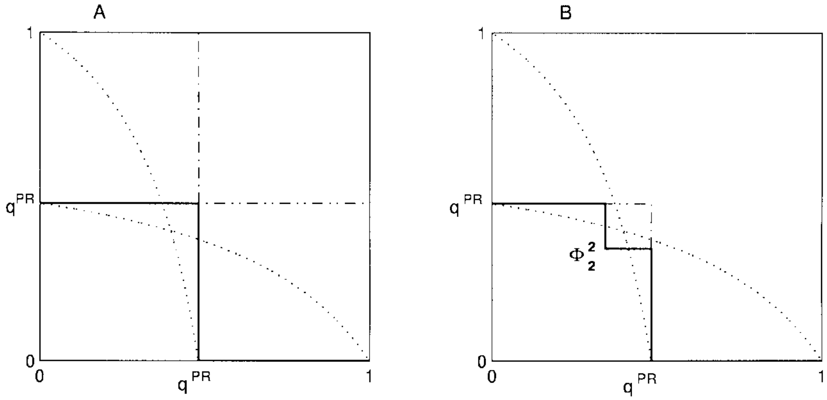

Figure 4
Banks' preferences and proposal

way similar to the one analyzed in Section 3.3. Before the types are realized, 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). Notice that the public and private schemes are decided upon simultaneously. Therefore the schemes are best responses to each other in equilibrium.

Proposition 5. *Given the public regulation of Proposition* 3, *it is optimal for the banks to propose net settlement for all types.*

The proposition shows that given the public scheme $\Phi_1^2(\cdot)$, it is optimal for the banks always to propose net settlement.[17] The supervisors then overrule the banks' proposal whenever at least one of the banks is of a type higher than q_1^2.

The information exchange could be profitable for the banks if they could agree on a type 1 scheme such that net settlement was proposed in an area smaller than $\Phi_1^2(\cdot)$. It is shown in the proof that this is not possible. The reason is that the banks face more severe incentive problems in the information exchange than the national supervisors. 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. For the banks, all types have the same incentive to pretend to be of a low type. This can also be seen in Figure 4A, where $\Delta W^i = 0$ is downward sloping while $\Delta \pi^i = 0$ (i.e., q^{PR}) is constant. As a result of this, if schemes of the same type are compared, the supervisors can implement a scheme that allows less net settlement than the corresponding private scheme.

4.3 Superior information

We now consider the polar assumption that the banks receive a perfect signal about each other's type. In this case there is no need for the banks to exchange information. The banks propose net settlement if and only if the foreign bank is of a type lower than or equal to q^{PR} as defined in Equation (11). The proposal made by the local bank thus reveals information to the supervisor about the foreign bank's type. Proposition 6 shows how the supervisors use this information to regulate better.

Proposition 6. *Suppose the banks can observe each other's type. The equilibrium of the game can be summarized as follows*:

(i) *banks propose net settlement if the foreign bank is of a type lower than or equal to* q^{PR},

[17] This is not the unique best response. For example, any scheme that proposes net settlement in a strictly larger area than $\Phi_1^2(\cdot)$ would also be a best response to $\Phi_1^2(\cdot)$. Furthermore, in the proof of Proposition 5 it is shown that there exists a scheme of type 2 which restricts the area of net settlement relative to $\Phi_1^2(\cdot)$, but gives rise to the same expected profits.

(ii) *for* $q_1, q_2 \leq q^{PR}$, *the supervisors implement the following scheme*:

$$\Phi_2^2(q_i) = \begin{cases} q^{PR} & \text{for } q_i \leq q_1^2 \\ q_1^2 & \text{for } q_1^2 < q_i \leq q^{PR}, \end{cases}$$

where q_1^2 *is the solution to* $\Delta W^i(q_1^2, \frac{1}{2}(q_1^2 + q^{PR})) = 0$.

The supervisors only regulate access to the net system if both banks are of a type lower than q^{PR}, as the banks otherwise do not agree on net settlement. Hence, whenever the supervisors are called to regulate access, they will hold the belief that the foreign bank is uniformly distributed on $[0, q^{PR}]$. At time 0, the supervisors choose the optimal scheme taking this updated belief as given. (In fact, it is irrelevant what the scheme looks like for types higher than q^{PR}.)

In the proof to Proposition 6 it is shown that the supervisors can only exchange information using a two-interval scheme of type 2. This scheme is illustrated in Figure 4B. We show that it is optimal to implement the scheme, as it denies access to the netting system when both banks are of a type close to q^{PR}, that is, of relatively high risk.

In this section we have considered a situation where the participants in the settlement system collect more information about the risk of their counterparts than the regulators. Our results show that under these circumstances it is important that both the banks and the public supervisors regulate access to the netting system. This is in line with the results of Rochet and Tirole (1996), who argue that the regulator of the payment system should also make use of the "finer information" that is acquired by market participants, provided these have the proper incentives. Our model shows that active involvement by market participants in regulation is desirable even if this latter requirement is not perfectly met, as it reveals valuable information to the regulator.

5. Conclusion

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 supervisors' decision whether to allow the banks to use a net settlement systems. As a novel feature, the communication between the national supervisors about the banks' risk was endogenized. We studied the access criteria that the banks and the supervisors would choose.

Both the public and private solutions were shown to be inefficient. The banks choose net settlement too often from a welfare point of view, because they face limited liability. Banks therefore do not take into account the additional cost of bankruptcy in the net system. The inefficiency of public access regulation stems from national supervision. The national supervisors' incentives are not perfectly aligned when deciding upon access, because the foreign economy carries some of the costs of failure in a net settlement system.

In equilibrium, these incentive problems imply that access regulation cannot be "fine tuned" in such a way that small changes in the banks' riskiness lead to a different access decision to the netting system. Still, the information exchange between the supervisors is shown to improve the efficiency of regulation, as it allows access to depend—at least to some degree—on the banks' riskiness.

We considered first the case where the banks have no more information about their foreign counterparts than the supervisors. In equilibrium, the supervisors impose stricter access criteria than the banks, so effectively regulation is done by the supervisors only. As an alternative scenario, it was assumed that the banks possess superior information about each other, say, because of a high degree of financial market integration. It is shown that even under this assumption the supervisors sometimes overrule the banks' proposal of net settlement. Here, however, private access regulation plays an important role as it reveals information to the supervisors. In general, joint regulation by market participants and public authorities is optimal.

We analyzed a situation where a bank failure does not lead to failure of the foreign counterpart. In Holthausen and Rønde (2000), the case is considered where the systematic impact of a failure is so high that failures can propagate through the netting system. It is shown that in this situation, the customers bear a larger part of the costs of a systemic crisis and the case for public regulation is stronger.

Finally, let us comment briefly on how our results relate to current regulatory practice. In the United States and Europe, the role of public payment system regulation is quite limited. The main role of the regulator is to ensure that certain risk-reducing measures are in place, while it is the payment system operator who decides on membership. Our model questions whether this "hands-off" policy toward payment system regulation is optimal, at least in an international environment, and suggests that active public involvement in access regulation is desirable. We have for simplicity considered a model with only three periods. Therefore the decision about access to the netting system is taken at the beginning of the game and is not revised later. We could instead have considered a model with a longer time horizon where the banks invest in the risky asset more than once. Here the supervisors should decide upon access every time the banks' portfolios change. The spirit of our results is thus that access should be reexamined periodically by the public authorities, and not be decided once and for all.

We showed that high-risk banks should be excluded from the net system. This seems to correspond to the way netting systems are operated in practice. In CHIPS, for instance, periodic revisions of the participants' financial situation take place. Finally, in many netting systems a system of debit caps is in place that allows the participants to reduce their exposure to counterpart failures. In our simple, linear model, however, banks and supervisors would always choose either no cap or a zero debit cap. The choice of whether to accept net settlement with the foreign bank can thus be reinterpreted as the choice of the optimal debit cap.

The article focused on the problem of regulating an international payment system. It might be possible to use the framework developed to analyze situations where similar two-sided communication problems arise. Obvious examples would be the supervision of international banks and information exchange between banks.

Appendix: Proofs of Propositions and Remarks

A.1 Proposition 1

Solving for $\Phi^{FB}(q_i)$ in Equation (8), we obtain

$$\Phi^{FB}(q_i)=\begin{cases}\dfrac{(2-q_i)(R-1)L-q_iR}{R+(R-1)L-2q_i(R-L)} & \text{for } q_i\leq\dfrac{2L(R-1)}{R+(R-1)L}\\ 0 & \text{otherwise.}\end{cases} \tag{12}$$

It follows readily from Equation (12) that $\Phi^{FB}(\cdot)$ is weakly decreasing in q_i and symmetric.

When deriving the constrained first-best scheme, we focus on symmetric schemes. The scheme is thus implementable as a Nash equilibrium if, assuming truth-telling by the supervisor in country j, truth-telling by the supervisor in country i can be induced. Since $\Phi^{FB}(q_i)$ is strictly decreasing for $q_i<\frac{2(R-1)L}{R+(R-1)L}$, it is implementable under asymmetric information iff. $\partial(\frac{\partial W^i}{\partial\Phi}/\frac{\partial W^i}{\partial t})/\partial q_i\leq 0$ [see Guesnerie and Laffont (1984)]. Differentiating Equation (9), we find that this is satisfied iff. $\Phi(q_i)\leq\frac{(R-1)L}{R-L}$ for all q_i.

Case (i). $R-L\leq RL$: It can be shown that $\Phi^{FB}(q_i)\leq\frac{(R-1)L}{R-L}$ for all q_i. Hence there exist transfers that induce truth-telling by the supervisor in country i. It follows that $\Phi^{FB}(\cdot)$ is implementable as a Nash equilibrium. The transfers are given by the differential equation $\frac{\partial t_i}{\partial q_i}=\Delta W^i(q_i,\Phi^{FB}(q_i))\frac{\partial\Phi^{FB}(q_i)}{\partial q_i}$ with $\frac{\partial\Phi^{FB}(q_i)}{\partial q_i}\big|_{q_i=\frac{2L(R-1)}{R+(R-1)L}}=0$.

Case (ii). $R-L>RL$: Since $\partial(\frac{\partial W^i}{\partial\Phi}/\frac{\partial W^i}{\partial t})/\partial q_i\underset{(>)}{\leq}0$ below (above) $\frac{(R-1)L}{R-L}$, a scheme has to be weakly increasing (decreasing) above (below) $\frac{(R-1)L}{R-L}$ to be implementable. Since $\Phi^{FB}(0)>\frac{(R-1)L}{R-L}$, the first-best scheme is thus not implementable. The constrained first-best scheme has one of the two following general forms:

$$\Phi^{CFB}(q_i)=\begin{cases}\tilde{q}_1 & \text{for } q_i\leq\tilde{q}_1\\ 0 & \text{otherwise}\end{cases}$$

where $\Phi^{FB}(0)\geq\tilde{q}_1\geq\frac{(R-1)L}{R-L}$ and $\int_0^{\tilde{q}_1}\frac{f(q_i)q_i\,dq_i}{F(\tilde{q}_1)}\leq\frac{(R-1)L}{R-L}$, or

$$\Phi^{CFB}(q_i)=\begin{cases}\hat{q}_3 & \text{for } q_i\leq\hat{q}_1\\ \hat{q}_2 & \text{for } \hat{q}_1<q_i\leq\min\{\Phi^{FB}(\hat{q}_2),\hat{q}_2\}\\ \Phi^{FB}(q_i) & \text{for } \min\{\Phi^{FB}(\hat{q}_2),\hat{q}_2\}<q_i\leq\hat{q}_2\\ \hat{q}_1 & \text{for } \hat{q}_2<q_i\leq\hat{q}_3\\ 0 & \text{otherwise}\end{cases}$$

where $\Phi^{FB}(0)\geq\hat{q}_3\geq\frac{(R-1)L}{R-L}\geq\hat{q}_2\geq\hat{q}_1\geq 0$, $\Phi^{FB}(\hat{q}_2)\geq\hat{q}_1$, and $\int_{\hat{q}_2}^{\hat{q}_3}\frac{f(q_i)q_i\,dq_i}{F(\hat{q}_3)-F(\hat{q}_2)}\,dq_i\leq\frac{(R-1)L}{R-L}$.

In the following, we sketch the proof for the characteriziation of the second type of scheme. The first type is characterized in an analogous way. First, consider q_i for which $\Phi^{CFB}(q_i)>\frac{(R-1)L}{R-L}$. Suppose that there exists an interval $[q',q'']$ st. $\Phi^{CFB}(\cdot)$ is increasing on $q_i\in(q',q'')$.

Then there exists a weakly increasing function, which has the same terminal points, but is uniformly closer to $\Phi^{FB}(\cdot)$. This contradicts $\Phi^{CFB}(\cdot)$ being the constrained optimal scheme. It follows that $\Phi^{CFB}(\cdot)$ is constant above $\frac{(R-1)L}{R-L}$.

Suppose that q' is a point of discontinuity st. $\Phi^{CFB}(q') > \frac{(R-1)L}{R-L}$ and $\Phi^{CFB}(q_i) < \frac{(R-1)L}{R-L}$ for $q_i \to q'_+$. Since the scheme is decreasing at q' it is implementable iff $\partial(\frac{\partial W^i}{\partial \Phi}/\frac{\partial W^i}{\partial t})/\partial q_i < 0 \Leftrightarrow \int_{\Phi^{CFB}(q'_+)}^{\Phi^{CFB}(q')} \frac{f(q_i)q_i\,dq_i}{F(\Phi^{CFB}(q'))-F(\Phi^{CFB}(q'_+))} \leq \frac{(R-1)L}{R-L}$.

Consider now q_i for which $q_i \leq \Phi^{CFB}(q_i) \leq \frac{(R-1)L}{R-L}$. The same type of argument as above can be used to establish that (i) on any interval where $\Phi^{CFB}(\cdot)$ is different from $\Phi^{FB}(\cdot)$ almost everywhere, $\Phi^{CFB}(\cdot)$ is constant; (ii) there cannot be a point of discontinuity q' for which $\frac{(R-1)L}{R-L} \geq \Phi^{CFB}(q') > \lim_{q_i \to q'_+} \Phi^{CFB}(q_i) > q_i$; and (iii) $\Phi^{CFB}(q_i) \leq \Phi^{FB}(q_i)$ for all q_i.

These results characterize $\Phi^{CFB}(\cdot)$ for $q_i \leq \Phi^{CFB}(q_i)$. $\Phi^{CFB}(\cdot)$ is defined for $q_i > \Phi^{CFB}(q_i)$ by symmetry. Here the scheme is also implementable, as it is decreasing and $\Phi^{CFB}(q_i) \leq \frac{(R-1)L}{R-L}$.

Finally, suppose $\Phi^{CFB}(0) > \Phi^{FB}(0)$. It would then be possible to improve upon $\Phi^{CFB}(\cdot)$ by choosing the first segment of the scheme such that $\Phi^{CFB}(0) = \Phi^{FB}(0)$. The resulting scheme would be implementable (also at the possible discontinuities) and give a strictly higher expected welfare. It follows that $\Phi^{CFB}(0) \leq \Phi^{FB}(0)$.

The transfers are given by the differential equation $\frac{\partial t_i}{\partial q_i} = \Delta W^i(q_i, \Phi^{CFB}(q_i))\frac{\partial \Phi^{CFB}(q_i)}{\partial q_i}$ with $\frac{\partial \Phi^{CFB}(q_i)}{\partial q_i}$ equal to the right-hand-side derivative at points where the derivative does not exist. At any of the possible points of discontinuity, $\hat{q}_i \in \{\hat{q}_1, \hat{q}_2, \hat{q}_3\}$, $\lim_{q_i \to (\hat{q}_i)_+}(t_i) = t_i(\hat{q}_i) + \int_{\hat{q}_{3-i}}^{\hat{q}_{4-i}} f(q_j)\Delta W^i(\hat{q}_i, q_j)\,dq_j$ (with $\hat{q}_0 = 0$).

From the general shape of the constrained first-best scheme, we can derive $\Phi^{CFB}(\cdot)$ for given parameters of the model by maximizing expected welfare wrt. $\tilde{q}_1$ and $\{\hat{q}_1, \hat{q}_2, \hat{q}_3\}$, respectively. Finally, we compare the expected welfare of the two candidate schemes. ■

A.2 Lemma 1

Denote country i's most preferred scheme $\Phi_i^*(\cdot)$. This is given by $\Delta W^i(q_i, \Phi_i^*(q_i)) = 0$ for all $q_i \in [0,1]$, $\Phi_i^*(q_i) \equiv \frac{(R-1)L(1-q_i)}{R-(R-L)q_i}$. Suppose there exists some $\hat{q}_i$ belonging to the open set $(\underline{q}, \bar{q})$ st. $\Phi(\hat{q}_i) < \Phi_i^*(\hat{q}_i)$. If $\Phi(\cdot)$ is strictly increasing on $(\underline{q}, \bar{q})$, there exists some ε st. $\Phi(\hat{q}_i) < \Phi(\hat{q}_i + \varepsilon) \leq \Phi_i^*(\hat{q}_i)$. A supervisor with a bank of type $\hat{q}_i$ would then have incentives to deviate and signal the type $\hat{q}_i + \varepsilon$. Similarly the supervisor would deviate to $\hat{q}_i - \varepsilon$ if $\Phi(\cdot)$ was strictly decreasing on $(\underline{q}, \bar{q})$. A similar argument applies to the case of $\Phi(\hat{q}_i) > \Phi_i^*(\hat{q}_i)$. Hence if $\Phi(\cdot)$ is strictly in- or decreasing on $(\underline{q}, \bar{q})$, the only scheme that can induce truth-telling by country i's supervisor is $\Phi(q_i) = \Phi_i^*(q_i)$ for all $q_i \in (\underline{q}, \bar{q})$. However, as $(\Phi_i^*)^{-1}(\cdot) \neq \Phi_i^*(\cdot)$, $\Phi(q_i) = \Phi_i^*(q_i)$ does not induce truth-telling by the supervisor in country j. ■

A.3 Proposition 2

We know from Lemma 1 that the scheme has to consist of constant segments. Therefore we divide the set $[0, \tilde{q}]$ into n intervals for which $\Phi_z^n(q_i)$ is constant, as explained in the proposition. The intervals are the same for country i and j, as the scheme is symmetric. Using Lemma 2, we obtain a system of $n-1$ equations, which determines the endpoint of the first $n-1$ intervals, $\{q_1^n, q_2^n, \ldots, q_{n-1}^n\}$. Since there are n intervals, but only $n-1$ constraints, there are two possible types of schemes. In schemes of type 1, $\Phi_1^n(0) = q_{n-1}^n$, while in those of type 2, $\Phi_2^n(0) = q_n^n = \tilde{q}$.

Because the schemes are constructed to satisfy Lemmas 1 and 2, there are no types that have an incentive to deviate to a neighboring interval. We can show, as in the proof of Lemma 2, that the single crossing condition $\frac{\partial \Delta W(q_i, \Phi(q_i))}{\partial q_i} \leq 0$ is satisfied for deviations to other than neighboring intervals. Thus the scheme is incentive compatible, as it is decreasing. ■

A.4 Corollary 1

For q_i and q_j uniformly distributed on $[0,1]$, $f(q_i) = f(q_j) = 1$ for $q_i, q_j \in [0,1]$ and $F(q_k^n) - F(q_{k'}^n) = q_k^n - q_{k'}^n$. Thus $E[q_j|I_k] = \frac{1}{q_k^n - q_{k'}^n}\int_{q_{k'}^n}^{q_k^n} f(q_j)q_j dq_j = \frac{1}{2}(q_k^n + q_{k'}^n)$. The systems of equations in Proposition 2 simplify to

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

and

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

for $h = 1, \dots, n-1$. To show that schemes of type 2 cannot exist, consider $h = 1$, and note that $q_n^n = 1$. q_1^n and q_{n-1}^n then need to satisfy $\Delta W^i(q_1^n, \frac{1}{2}(q_{n-1}^n + 1)) = 0$. Because of Assumption 1, one can show that $\Delta W^i(q_1^n, \frac{1}{2}(q_{n-1}^n + 1)) < 0$ for any $0 < q_1^n \leq q_{n-1}^n < 1$. ■

A.5 Proposition 3

Step 1. Existence and uniqueness of the type 1 scheme with two intervals, $\Phi_1^2(\cdot)$.

From Proposition 2 it follows that q_1^2 is given as the solution to $\Delta W^i(q_1^2, \frac{1}{2}q_1^2) = 0$. It can be shown that for $q_1^2 \in (0, 1)$ this equation has exactly one solution:

$$q_1^2 = \frac{\frac{1}{2}R + (R-1)L - \sqrt{(\frac{1}{2}R + (R-1)L)^2 - 2(R-L)(R-1)L}}{R-L}. \tag{13}$$

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

Since $\Delta W^i(q_i, q_j) = 0$ is downward sloping, for $\Delta W^i(x_1, y_1) = 0$ and $\Delta W^i(x_2, y_2) = 0$, we have $x_1 < x_2 \Longleftrightarrow y_1 > y_2$. From Corollary 1, we know that if $\Phi_1^2(\cdot)$ and $\Phi_1^n(\cdot)$ exist, we have $\Delta W^i(q_1^2, \frac{1}{2}q_1^2) = 0$ and $\Delta W^i(q_{n-1}^n, \frac{1}{2}q_1^n) = 0$. Since $q_1^n \leq q_{n-1}^n$, it follows that $q_1^n \leq q_1^2 \leq q_{n-1}^n$.

Step 3. If Assumption 1 holds, $\Phi_1^n(\cdot)$, $n > 2$, *does not exist.*

Consider the set of variables x_1, x_2, x_3, and x_4 satisfying

$$\begin{aligned} \Delta W^i\left(x_1, \frac{1}{2}(x_2 + x_3)\right) &= 0 \\ \Delta W^i\left(x_2, \frac{1}{2}(x_1 + x_4)\right) &= 0 \end{aligned} \tag{14}$$

Solve the first equation in Equation (14) for x_1 as function of x_2 and x_3, $x_1(x_2, x_3) = \frac{2(R-1)L - R(x_2+x_3)}{2(R-1)L-(R-L)(x_2+x_3)}$. From the second equation, we obtain x_4 as a function of x_2 and x_3: $x_4(x_2, x_3) = \frac{2(R-1)L(1-x_2)}{R-(R-L)x_2} - x_1(x_2, x_3)$. From here, $\frac{\partial x_4}{\partial x_2} = \frac{-2(R-1)L^2}{[R-(R-L)x_2]^2} + \frac{2(R-1)L^2}{[2(R-1)L-(R-L)(x_2+x_3)]^2}$. It follows

$$\frac{\partial x_4}{\partial x_2} > 0 \Longleftrightarrow R - 2(R-1)L + (R-L)x_3 > 0. \tag{15}$$

Now take $x_1 = q_{n-1}^n$, $x_2 = q_1^n$, $x_3 = 0$, and $x_4 = q_{n-2}^n$. For $\Phi_1^n(\cdot)$, $n > 2$, to exist, these variables have to satisfy Equation (14). From Equation (15) and Assumption 1, it follows $\frac{\partial q_{n-2}^n}{\partial q_1^n} > 0$. Furthermore, by definition $q_1^n \leq q_{n-2}^n < q_{n-1}^n$ needs to be satisfied. We now show that we cannot find any combination of $\{q_1^n, q_{n-2}^n, q_{n-1}^n\}$ satisfying Equation (14) for which this is true. Because of step 2, $q_1^n \in (0, q_1^2)$. At $q_1^n = q_1^2$, we have $q_{n-1}^n = q_1^2$ and $q_{n-2}^n = 0$. However, since q_{n-2}^n is increasing in q_1^n, it must be that $q_{n-2}^n < 0 < q_1^n$ for all relevant q_1^n. Hence no solution to $\Phi_1^n(\cdot)$, $n > 2$, exists. ■

A.6 Proposition 4

We need to show that $\Phi_1^2(\cdot)$ leads to a higher expected welfare than would always choosing gross or net settlement. Under $\Phi_1^2(\cdot)$, the supervisors can always obtain gross settlement by signaling $q_i = 1$. It follows from a revealed preference argument that $\Phi_1^2(\cdot)$ gives higher expected welfare than always imposing gross settlement. Next, we show that $\Phi_1^2(\cdot)$ also dominates net settlement.

Let $\bar{q}$ be the endpoint of the first interval in a type 1 scheme with two intervals (possibly different from $\Phi_1^2(\cdot)$). The expected welfare as a function of $\bar{q}$ is given as

$$W^i(\bar{q}) = \int_0^{\bar{q}} \int_0^{\bar{q}} W_N^i dq_j dq_i + \int_0^{\bar{q}} \int_{\bar{q}}^1 W_G^i dq_j dq_i + \int_{\bar{q}}^1 \int_0^1 W_G^i dq_j dq_i.$$

Integration and maximization yields the first-order condition: $\bar{q}^2(R-L) - \frac{3}{2}\bar{q}(R+(R-1)L) + 2(R-1)L = 0$. It can be shown that there is only one solution to this equation in $[0, 1]$. Denote this solution q^*. Analysis of the first-order condition shows that welfare increases up to $\bar{q} = q^*$ and decreases afterward. Calculations show that $q_1^2 > q^*$. Hence net settlement for all (q_1, q_2) gives lower expected welfare than $\Phi_1^2(\cdot)$. Proposition 4 follows. ■

A.7 Proposition 5

In the first step of the game, the banks propose how to settle payments. They can either decide to propose net or gross settlement for all types, or they can exchange information by agreeing on a scheme $\Phi_i^{PR}(\cdot)$. As before, we restrict attention to symmetric, incentive-compatible, and piece-wise continuous schemes. Assuming that the supervisors have agreed on $\Phi_1^2(\cdot)$, we are looking for a Nash equilibrium where the private and the public scheme are optimal, taking the other scheme as given.

Consider private schemes, $\Phi_i^{PR}(\cdot)$, where the proposal made depends on the types realized. The only relevant part of the scheme is for $q_i, q_j \leq q_1^2$ (where net settlement is allowed), so we consider only types that are distributed between 0 and q_1^2. The proof is analogous to the one of Proposition 2, so steps have been omitted. First, we find that any incentive compatible scheme consists of constant segments with jumps. Second, consider q' and q'', $q' \neq q''$, for which $\Phi^{PR}(q') \neq \Phi^{PR}(q'')$. Define $\Delta\pi^i(q_i, q_j) \equiv \pi_N^i(q_i, q_j) - \pi_G^i(q_i)$. Incentive compatibility requires that $\Phi(q')\Delta\pi^i(q', \frac{1}{2}\Phi(q')) = \Phi(q'')\Delta\pi^i(q'', \frac{1}{2}\Phi(q''))$. Rewriting yields

$$\frac{1}{2}(\Phi(q') + \Phi(q'')) = q^{PR}, \tag{16}$$

with q^{PR} defined by Equation (11). Symmetry requires that $\Phi^{PR}(\cdot)$ is nonincreasing, and Equation (16) implies directly that there can be only one jump; that is, the scheme consists of maximally two intervals. Thus only two types of schemes are possible:

$$\Phi_1^{PR}(q_i) = \begin{cases} q_1^{PR} & \text{for } q_i \leq q_1^{PR} \\ 0 & \text{otherwise.} \end{cases} \text{ (type 1), } \quad \text{or} \quad \Phi_2^{PR}(q_i) = \begin{cases} q_1^2 & \text{for } q_i \leq q_2^{PR} \\ q_2^{PR} & \text{otherwise.} \end{cases} \text{ (type 2),}$$

where $q_i^{PR} < q_1^2$, $i = 1, 2$. Consider first $\Phi_1^{PR}(\cdot)$. Straightforward calculations show $q_1^2 > q^{PR} > \frac{1}{2}q_1^2$. This implies that there is no q_1^{PR} satisfying Equation (16), so $\Phi_1^{PR}(\cdot)$ does not exist.

Second, consider the scheme $\Phi_2^{PR}(\cdot)$. We find that there exists a $q_2^{PR} < q_1^2$ satisfying Equation (16). However, as Equation (16) holds, the banks are indifferent between settling net according to $\Phi_2^{PR}(\cdot)$ or $\Phi_1^2(\cdot)$. Implementing $\Phi_2^{PR}(\cdot)$ gives the same expected profit as proposing net settlement for all q_i, q_j. Hence it is optimal to agree on a scheme that proposes either net or gross settlement for all types realized.

Finally, foreseeing the public regulation, the banks prefer to propose net 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 $\frac{1}{2}q_1^2 < q^{PR}$, banks prefer net settlement whenever the supervisor allows it. ■

A.8 Proposition 6

The supervisors know that banks propose net settlement iff. $q_i, q_j \leq q^{PR}$. Thus their updated belief given that the banks propose net settlement is that the risk of the foreign bank is uniformly distributed on $[0, q^{PR}]$.

First, we show that the supervisors can only exchange information using the scheme $\Phi_2^2(\cdot)$. Consider schemes of type 1. $\Phi_1^2(\cdot)$ does not exist, as q_1^2 given by $\Delta W^i(q_1^2, \frac{1}{2}q_1^2) = 0$ is larger than q^{PR}. Then, from the proof of Proposition 3, no type 1 scheme can exist.

For schemes of type 2, note that q_1^2 is determined by $\Delta W^i(q_1^2, \frac{1}{2}(q_1^2 + q^{PR})) = 0$. Straightforward calculations show that this equation has a unique solution for which $0 < q_1^2 < q^{PR}$, so $\Phi_2^2(\cdot)$ exists. Now, consider $\Phi_2^n(\cdot)$, $n > 2$. First, using the same argument as in step 2 of Proposition 3, we obtain $q_{n-1}^n \in (q_1^2, q^{PR})$. Furthermore, $q_2^n \leq q^{PR}$ needs to hold. Take $x_1 = q_1^n$, $x_2 = q_{n-1}^n$, $x_3 = q^{PR}$, and $x_4 = q_2^n$. These variables have to satisfy Equation (14). Using Equation (14), we find that for $q_{n-1}^n = q_1^2$, we have $q_1^n = q_1^2$ and $q_2^n = q^{PR} > q_{n-1}^n$. To show that an equilibrium with three or more intervals cannot exist, it then suffices to show that $\frac{\partial q_2^n}{\partial q_{n-1}^n} > 0$, as then, $q_2^n > q^{PR}$ for all $q_{n-1}^n \in (q_1^2, q^{PR})$. From Equation (15), we know that this is true iff. $R - 2(R-1)L + (R-L)q^{PR} > 0$. This condition reduces to $R(R+L)(1-L) + L^2 > 0$, which is always satisfied. Hence $\Phi_2^n(\cdot)$, $n > 2$ do not exist.

Finally, $\Delta W^i(q_1^2, \frac{1}{2}(q_1^2 + q^{PR})) = 0$ and $\partial^2 W^i / \partial\Phi\partial q < 0$ imply that gross settlement leads to higher welfare than net settlement for $q_i, q_j \in (q_1^2, q^{PR}]$. ■

References

Bank for International Settlements, 1989, "Report on Netting Schemes" (Angell Report), prepared by the Group of Experts on Payment Systems of the Central Banks of the G-10 countries, Basel.

Bank for International Settlements, 1990, "Report of the Committee on Interbank Netting Schemes of the Central Banks of the Group of Ten Countries" (Lamfalussy Report), Basel.

Bank for International Settlements, 1993, "Central Bank Payment and Settlement Services with Respect to Cross-Border and Multi-Currency Transactions" (Noël Report), Basel.

Crawford, V. P., and J. Sobel, 1982, "Strategic Information Transmission," *Econometrica*, 50, 1431–1451.

European Central Bank, 1999, *Monthly Bulletin*, December 1999.

Freixas, X., and B. Parigi, 1998, "Contagion and Efficiency in Gross and Net Interbank Payment Systems," *Journal of Financial Intermediation*, 10, 3–31.

Giovannini, A., 1992, "Central Banking in a Monetary Union: Reflections on the Proposed Statute of the European Central Bank," in *The Debate on Money and Europe*, MIT Press, Cambridge, MA.

Guesnerie, R., and J. Laffont, 1984, "A Complete Solution to a Class of Principal-Agent Problems with an Application to the Control of a Self-Managed Firm," *Journal of Public Economics*, 25, 329–369.

Holthausen, C., and T. Rønde, 2000, "Regulating Access to International Large Value Payment Systems," Working Paper No. 22, European Central Bank.

Kahn, C., and W. Roberds, 1998, "Payment System Settlement and Bank Incentives," *Review of Financial Studies*, 11, 845–870.

Masciandaro, D., and L. Capella, 1999, "Comparing National Deposit Insurance Systems," mimeo, Universita Bocconi, Milano.

Melumad, N. D., and T. Shibano, 1991, "Communication in Settings with No Transfers," *RAND Journal of Economics*, 22, 173–198.

Rochet, J.-C., and J. Tirole, 1996, "Controlling Risk in Payment Systems," *Journal of Money, Credit and Banking*, 28, 832–862.

Schoenmaker, D., 1995, "Banking Supervision in Stage Three of EMU," Special Paper No. 72, LSE Financial Markets Group, London.

Stein, J. C., 1989, "Cheap Talk and the Fed: A Theory of Imprecise Policy Announcements," *American Economic Review*, 79, 32–42.

Summers, B., 1991, "Clearing and Payment Systems: The Role of the Central Bank," *Federal Reserve Bulletin*, 77, 81–91.