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Abstract

Rules for settling interbank payments matter in an economic sense because they can determine an ordering of claims on bank assets. This paper examines the incentive effects of three different types of settlement rules on banks' portfolio decisions: gross settlement, net settlement, and gross settlement combined with queuing. A gross settlement system where settlement is delayed can create incentives for banks to hold excessively risky portfolios, because the downside risk is shifted to other banks. This incentive can be limited through either the elimination of lags in settlement, or in some cases by introducing net settlement. Likewise, use of a queuing system can limit risk-shifting behavior. The effectiveness of queuing systems in constraining banks' incentives is limited by the size and pattern of interbank payments. For some payment configurations, a queuing system will not effectively constrain risk-shifting.

Key words: Settlement, payment, queuing

JEL classification: G210, G280

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1. INTRODUCTION

Rules for settling interbank payments matter in an economic sense because they determine an ordering of claims on bank assets. That is, in virtually all modern legal systems, transfers of bank funds are difficult, costly, or often impossible to reverse or "avoid," once they have been settled. Since different settlement rules imply different priorities of competing claims, it is reasonable to expect that the economic behavior of banks will vary according to the rules of the payment systems in which they participate.

Historically, payments among banks have been settled on a net basis.[1] In a net settlement system, banks exchange payment obligations over a certain period of time, usually over the course of a business day. At a designated interval, the "payment system" calculates each bank's net position vis-à-vis all the other banks in the system. Each bank in a net debit or due-to position discharges its settlement obligation by transferring an acceptable settlement medium (before 1930 specie or the equivalent, more recently central bank funds) to the payment system, in an amount equal to the value of the bank's due-to position. The payment system in turn transfers the appropriate amount of the settlement medium to banks who are in a net credit or due-from position.

The chief alternative to net settlement is gross settlement. In a gross settlement system, each payment obligation must be settled by a transfer of an offsetting amount of the appropriate settlement medium.

The historical popularity of net settlement is easily explainable, given that net settlement offers certain advantages over gross. First, for a particular set of payment transactions, net settlement economizes on the use of a costly settlement medium such as a commodity money or fiat outside money. Second, net settlement can reduce the likelihood of coordination failures in either settlement or trading (Kobayakawa 1997 or Angelini 1998). Possible coordination failures can take the form of payment delays, or in extreme cases complete gridlock, in which every bank waits for another bank to send in the first payment. Third, since payments among banks tend to be mutually offsetting, net settlement can reduce the leverage associated with the exchange of interbank claims, and thereby reduce incentive problems associated with such leverage.

The principal disadvantage of a net settlement system is that in this type of system the central counterparty, i.e., in the payment system itself, ends up bearing most of the credit risk and liquidity risk associated with the settlement of payment obligations (Angelini and Giannini 1994, Emmons 1995, Schoenmaker 1995). Since the payment system must be liquid and solvent in order for settlement to occur, careful monitoring and control of these risks is required. Historically, banks participating in net settlement systems have tried to limit these risks through means such as membership requirements, position limits, collateral requirements, and the like.

Despite banks' historical preference for net settlement, however, recent trends in large-value payment systems have been towards increased regulation of net settlement systems, and also towards migration of large-value payments from net settlement systems to real-time gross settlement or RTGS systems (a real-time gross settlement system is a gross settlement system where payments can be made over the course of the day and not just at specified times). While there are a number of potential explanations for this trend,[2] perhaps the most important is the explosion in the volume of payments associated with financial markets. In the case of many large-value payment systems, the gross value of payments cleared within a few days' time commonly exceeds the value of *annual* nominal GDP in the appropriate currency.[3] Given this unprecedented volume of payments, it would be difficult to precisely determine and price the risks associated with modern large-value payment systems. In the absence of precise models, central banks have tried to make these systems more robust against shocks, by encouraging increased use of RTGS systems and by imposing requirements such as the Lamfalussy standards on net settlement systems.[4]

A properly designed RTGS system can minimize the liquidity and credit risks associated with settlement. Such systems may impose undue costs on banks, however, if the opportunity cost of holding central bank liabilities is high. Central banks have tried to lessen the costs of using RTGS systems by making intraday credit available to banks participating in these systems. So that the RTGS systems do not end up being effectively net settlement systems, central banks have generally seen fit to place restraints on banks' use of intraday credit, however. These restraints have taken the form of position limits, collateral requirements, and intraday interest charges.[5] Since these restraints also impose costs on banks, banks have an incentive to create new designs of payment systems that attempt to improve the risk /liquidity cost tradeoff over what is available with current systems.

One type of arrangement that has received some attention lately has been the use of queuing algorithms in combination with RTGS payment systems (see Bank for International Settlements 1997). The basic idea is as follows. Under this type of system, a payment instruction need not be settled as soon as it is communicated to the payment system. If insufficient liquidity is available, then the payment is sent to a centralized queue. As additional payments flow in, the originating bank's stock of central bank funds may increase to the point where the queued payment can be settled. More sophisticated versions of queuing algorithms look for either bilateral or multilateral matches among queued payments, so that de facto some offset of obligations occurs, although perhaps less than would occur under a net settlement system.

Very little work has been done to investigate the properties of payment systems that combine RTGS with queuing. As noted above, the fundamental question that needs to be addressed is in what sense RTGS systems with queuing offer improvements over either net settlement or RTGS without queuing, in terms of the relevant tradeoffs. Particularly unclear is the impact of queuing arrangements on banks' portfolio decisions. Since banks' portfolios are typically not observable by outsiders on an intraday basis, systems that incorporate queuing may generate incentives for banks to lever their portfolios by taking large intraday positions vis-à-vis other banks. A similar incentive can exist in other types of payment systems, but depending on the rules for settlement in each type of system, different consequences could result.

Below, I develop a very simple model for analyzing banks' portfolio decisions in various types of payment systems, including net settlement systems, and gross settlement systems both with and without delivery-versus-payment requirements. The model sacrifices some realism so that the value of interbank claims can be readily derived using "Black-Scholes" pricing. Using the model, I verify that a properly designed gross settlement system can eliminate risk but may result in unacceptable costs, relative to the costs of potential defaults associated with a net settlement system.

The model is then used to analyze the impact of a system that nominally operates as a gross settlement system, but also allows banks the option of entering payments into a queue. Queued payments may be either offset during the day or settled on a gross basis at the end of the day. For the examples I construct, it then turns out that such a system either causes banks to make the same portfolio decisions as under net settlement, or results in banks taking on more risk than under net settlement, leading to a welfare loss. A final section relates the model results to Japanese payment institutions and offers suggestions for future research.

2. THE MODEL ENVIRONMENT

There are N agents known as "banks," where N is large. Banks will trade consumption claims over a single trading day. Initially I will assume that all trading takes place at the beginning of the day ($t = 0$). There is a single final good which is consumed at the end of the day ($t = 1$), and there are many intermediate goods. Banks are risk-neutral and seek to maximize their expected end-of-day consumption of the final good.

Banks are endowed with one unit of an intermediate good. Banks also have access to two production technologies. Using the first technology, banks can instantaneously produce one unit of a specific type of intermediate good at $t = 0$, and producing one unit of this good incurs a cost (disutility) of one unit in terms of the final good.

Using the second technology, a bank can take one unit of an intermediate good at $t = 0$ and produce a random amount of the final good over the course of the day. Final good production always requires an intermediate good input of exactly one unit. The expected output of the final good, as of $t = 0$, given a unit of appropriate input, is designated as V. Banks cannot produce intermediate goods for their own final good production, so these must be purchased from other banks, using claims issued by the producing bank. Consistent with real-world practice, interbank claims arising from trading will be debt claims.[6] Each debt claim will consist of a prior claim on the issuing bank's production of final goods. Specifically, a bank supplying intermediate goods will be paid in full when its debtor produces an amount of the final good by the end of the day that is sufficient to discharge the debt obligation.[7] The intermediate good supplier will receive all of the debtor's final good production when the debtor's production does not cover the debt claim. If a bank is both a debtor (final good producer) and a creditor (intermediate good producer), then the bank's creditor does not have any claim on repayments by the bank's debtor. Instead, to avoid having to set complex priority rules in cases of multiple defaults, I will assume that repayments of debt to a defaulting bank are not attachable by other banks. In practice, this situation could easily arise, for example, if the claims of other parties such as depositors or regulators have priority over interbank claims in cases of default.

Following Flannery (1994), Gorton (1996), and Kahn and Roberds (forthcoming), the value of debt claims on a bank's production (i.e., "portfolio") will be calculated using a variant of the model developed in Merton (1974). Between $t = 0$ and $t = 1$, the value of the bank's production evolves according to

$$dV = \alpha V dt - \sigma V dz \tag{1}$$

where α and σ are positive, and z is a standard Wiener process. Banks have no control over the instantaneous expected return on their production α, but at time $t = 0$, each bank can choose the instantaneous variance of its portfolio σ^2. I assume that each bank makes its choice of σ^2 before the start of trading.

Trading proceeds as follows. At time $t = 0$, banks arrange for the delivery of an intermediate good, issuing the intermediate good supplier a debt claim with face value *B*. Applying Merton's pricing formulas (in the case where the debt maturity equals one period), the value of the typical bank's equity claim as of $t = 0$ is given by $f(V, B, \sigma^2)$, where

$$f = V\Phi(x_1) - B\Phi(x_2) \tag{2}$$

$$x_1 = \sigma^{-1}\log(V / B) + \tfrac{1}{2}\sigma \tag{3}$$

$$x_2 = \sigma^{-1}\log(V / B) - \tfrac{1}{2}\sigma \tag{4}$$

and Φ is the standard normal distribution function. The $t = 0$ value of the intermediate good producer's debt claim on the other bank is given by $F \equiv V - f$. Equation (2) is a special case of the well-known Black-Scholes option pricing formula, and the following results are well known:

$$\frac{\partial f}{\partial B} < 0; \frac{\partial F}{\partial B} > 0 \tag{5}$$

$$\frac{\partial f}{\partial \sigma^2} > 0; \frac{\partial F}{\partial \sigma^2} < 0 \tag{6}$$

$$\frac{\partial f}{\partial V}, \frac{\partial F}{\partial V} > 0 \tag{7}$$

Merton (1974) does not specify any relationship between the initial portfolio value *V* and the instantaneous variance σ^2. Since each bank's production is of limited scale, I will assume that *V* is maximized for some $\sigma_m^2 > 0$, so that for values of $\sigma^2 > \sigma_m^2$, *V* actually decreases. Formally, *V* is taken to be a linear, decreasing function of σ^2 over the interval $\left[\sigma_m^2, \sigma_u^2\right]$:

$$V\left(\sigma^2\right) = a - b\sigma^2$$

where *a* and *b* are positive constants, and $V(\sigma_m^2) > 1$.

3. SETTLEMENT AND BANK INCENTIVES

After trading has occurred at $t = 0$ and debt claims have been issued, these claims must be settled at the end of the trading day. Below, I consider the effects of a number of different settlement procedures on banks' portfolio allocations.

Gross Settlement without Delivery-versus-Payment

I initially consider the simplest possible type of settlement procedure, in which debt claims are extinguished by exchange of offsetting amounts of the final good at the end of the trading day. This settlement procedure will be interpreted as "gross settlement," although in modern gross settlement systems, gross settlement is in outside money (central bank funds) and not goods.[8] The final good as described above possesses the money-like property that everyone is willing to hold it, however, so settlement in the final good will be used as a proxy for monetary settlement. Since intermediate goods are delivered at the beginning of the day and settlement occurs at the end of the day, in this case interbank settlement cannot take place on a delivery-versus-payment (DVP) basis, as this term is often understood.[9]

Individual rationality on the part of intermediate good suppliers requires that banks supplying an intermediate good receive a debt claim of value equal to the cost of producing the intermediate good, i.e., that

$$F\left(V(\sigma^2), B, \sigma^2\right) \geq 1 \tag{8}$$

A difficulty associated with constraint (8) is that while intermediate good suppliers can readily ascertain the face value of their debt claims *B*, they cannot observe the instantaneous variance σ^2 of their debtor's portfolio, since banks' portfolios are "opaque." Of course, banks are free to report values of σ^2 to their creditor, but reported values are not likely to be verifiable by the creditor, at least over the short horizons associated with intraday trading.

If banks' choices of σ^2 were verifiable, then each bank would make its portfolio decision by simply maximizing the value of its equity position, subject to its creditor's individual rationality constraint (8), i.e., the typical bank's portfolio problem would be[10]

$$\max_{B,\sigma^2} f\left(V(\sigma^2), B, \sigma^2\right) \tag{9}$$

subject to individual rationality of the bank's suppliers, i.e.,

$$V(\sigma^2) - f\left(V(\sigma^2), B, \sigma^2\right) \geq 1 \tag{10}$$

and feasibility of the portfolio strategy, i.e.,

$$\sigma_m^2 \leq \sigma^2 \tag{11}$$

$$\sigma^2 \leq \sigma_u^2 \tag{12}$$

$$B \geq 0 \tag{13}$$

In this case, it is easy to show that the first-best outcome obtains.

Lemma 1. Suppose that each bank's choice of σ^2 *is verifiable by its intermediate good supplier. Then under gross settlement without DVP, banks will choose* $\sigma^2 = \sigma_m^2$, *i.e.,* σ^2 *is chosen so as to maximize the expected value of each bank's final good production. The* *face value of the debt held by the intermediate good supplier* B_m *will be defined implicitly by*

$$V(\sigma_m^2) - f\left(V(\sigma_m^2), B_m, \sigma_m^2\right) = 1 \qquad (14)$$

Proof: Clearly the supplier's individual rationality constraint will only be satisfied for $B > 0$, so we ignore constraint (13). First-order conditions for problem (9)-(13) are given by

$$(f_V V' + f_{\sigma^2})(1-\lambda) + V'\lambda + \mu - \nu \le 0 \qquad (15)$$

$$f_B(1-\lambda) \le 0 \qquad (16)$$

where λ, μ, and ν are Lagrange multipliers associated with constraints (10), (11) and (12). Since only positive values of B are feasible, (16) holds with equality, implying that $\lambda = 1$ and that (10) and hence (15) will hold with equality. Since $V' < 0$, this can only happen if $\mu > 0$, i.e., if $\sigma^2 = \sigma_m^2$.

Q.E.D.

While Lemma 1 provides a useful benchmark, non-verifiability of banks' portfolio decisions implies that banks would not necessarily choose σ_m^2 and B_m. If a bank issued a debt claim of B_m for its creditor good, then it could have an incentive to choose an instantaneous variance for its portfolio in excess of σ_m^2. This would occur if the following condition were satisfied for $\sigma^2 = \sigma_m^2$ and $B = B_m$:

$$\frac{\partial f}{\partial \sigma^2} = f_V V' + f_{\sigma^2} = f_{\sigma^2} > 0 \qquad (17)$$

In other words, under condition (17), a debtor bank has an incentive to take on extra risk, in order to maximize the value of the leverage afforded by the interbank debt claim.

Thus, in choosing whether to accept a debt claim in return for provision of an intermediate good, a creditor bank must take into account the incentives created by leverage. In particular, the design of the contract should take into account the fact that a debtor bank will never voluntarily choose a value of σ^2 that will lower the value of its equity claim.

To avoid certain complications which can arise in this type of contracting problem, an additional technical assumption is necessary:[11]

Assumption A1. Let B_u be the largest feasible face value of the debt, i.e., let B_u be the face value of the debt that satisfies individual rationality constraint (8) at equality for $\sigma^2 = \sigma_u^2$. Then condition (17) is satisfied for all feasible values of σ^2 and B, i.e., (17) holds for $\sigma_m^2 \le \sigma^2 \le \sigma_u^2$ and $0 \le B \le B_u$.

Assumption *A1* requires that the initial value of the bank's project *V* not decline too quickly as its risk σ^2 increases, i.e., the parameter *b* must be positive but sufficiently small. Under *A1*, the following proposition describes banks' behavior under gross settlement but without DVP.

Proposition 1. Suppose that each bank's choice of σ^2 is not verifiable by its intermediate good supplier and that assumption A1 holds. Then under gross settlement without DVP, banks will choose a riskier portfolio and a higher face value of debt than if σ^2 were verifiable, i.e., banks will choose $\sigma^2 = \sigma_u^2 > \sigma_m^2$ and $B = B_u > B_m$.

Proof. Suppose by way of contradiction that a bank chooses $\sigma^2 < \sigma_u^2$, and chooses *B* so that individual rationality constraint (8) is satisfied at equality. Then, under assumption

A1, a debtor bank can always increase the value of its equity claim *f* by increasing σ^2, without this increase being observed by prospective creditors. But an increase in risk without an increase in the promised rate of return (face value) of the debt would violate individual rationality for the creditors. Hence, debtor banks will choose $\sigma^2 = \sigma_u^2$, and creditors will receive debt with face value B_u that satisfies (8) at equality for $\sigma^2 = \sigma_u^2$.

Q.E.D.

Proposition 1 says that since banks' portfolios are opaque, under gross settlement without DVP banks will have an incentive to choose riskier portfolios than they would if the quality of their portfolios were verifiable by their creditors. Banks are willing to take on more risk because the downside of the risk can be shifted to the banks' creditors. As a result, banks are willing to forego some expected return on their portfolios in order to obtain additional option value. A welfare loss results, relative to full information, since $V(\sigma_u^2) < V(\sigma_m^2)$.

Gross Settlement with Delivery versus Payment

One means of limiting leverage resulting from interbank payment obligation would be to institute a strict delivery-versus-payment requirement. Under this strict form of DVP, banks would be required to immediately settle any obligation by means of an offsetting transfer of the final good.

To incorporate this type of settlement procedure into the model, some modification of the basic setup is necessary. Accordingly, suppose that the technology for producing the final good allows for "early liquidation" of some or all of a banks' portfolio. In other words, banks can liquidate a portion of their production project to obtain final goods at $t=0$, given a unit input of an intermediate good. However, in the tradition of the banking literature (e.g., Diamond and Dybvig 1983), I will assume that immediate liquidity entails a cost. Specifically, if a fraction *x* of a banks' portfolio is liquidated early then only $x\delta V$ units of final goods are obtained, where $V(\sigma_m^2)^{-1} < \delta < 1$. Gross settlement with DVP is then feasible, but at a cost.

Proposition 2. Under gross settlement with DVP, banks will choose $\sigma^2 = \sigma_m^2$, *i.e.,* σ^2 *is chosen so as to maximize the expected value of their final good production.*

Proof: Under DVP, at $t=0$ each bank makes its portfolio decision σ^2, liquidates a large enough fraction $\left(\delta V(\sigma^2)\right)^{-1}$ of its portfolio to pay off its intermediate good supplier, and then holds the remaining portion of its portfolio until maturity ($t=1$). Hence a bank's expected final good consumption is given by

$$V(\sigma^2)\left[1-\left(\delta V(\sigma^2)\right)^{-1}\right] = V(\sigma^2) - \delta^{-1} \tag{18}$$

which is clearly maximized at $\sigma^2 = \sigma_m^2$.

Q.E.D.

Thus, under gross settlement with DVP, banks choose the first-best portfolio allocation, but incur losses as they liquidate part of their portfolio to comply with the DVP requirement. As a result, requiring DVP either may or may not result in a welfare gain, depending on the costs of liquidity. From Propositions (2) and (3), it follows that gross settlement with DVP will be socially preferred to gross settlement without DVP iff

$$V(\sigma_m^2) - V(\sigma_u^2) > \delta^{-1} - 1 \tag{19}$$

In words, DVP is preferred iff the cost of incentive problems associated with leverage exceeds the cost of early liquidation.

An alternative interpretation of the model of this section is as a model of gross settlement with DVP, where intraday credit is provided by the central bank and where all intraday credit must be completely collateralized. Under this interpretation, the portion of each bank's portfolio that is liquidated at $t = 0$ is not used directly as a means of settlement, but is instead posted with the central bank as collateral. The cost parameter δ represents the cost of converting bank assets to eligible collateral. The formal analysis remains the same under the alternative interpretation.

Finally, the following result should be noted:

Corollary to Proposition 2. If the cost of liquidation is sufficiently low (if δ is sufficiently close to unity), then banks will voluntarily institute DVP, i.e., they will settle their obligations at $t = 0$.

Proof: Suppose that there is no DVP requirement. From Proposition 1, if a bank does not settle early, its expected final good consumption will be

$$f\left(V(\sigma_u^2), B_u, \sigma_u^2\right) = V(\sigma_u^2) - F\left(V(\sigma_u^2), B_u, \sigma_u^2\right) = V(\sigma_u^2) - 1 \qquad (20)$$

where the last equality follows from the individual rationality constraint (8) at equality. If a bank does settle early, then Proposition 2 says that the bank can expect final good consumption of

$$V(\sigma_m^2) - \delta^{-1} \qquad (21)$$

As $\delta \uparrow 1$, then (21) must exceed (20) since $V(\sigma_m^2) > V(\sigma_u^2)$.

Q.E.D.

The Corollary says that banks will want to settle early for sufficiently low costs of liquidity. Banks are willing to do this because, for low costs of liquidity, the "option value" of settling later in the day is exceeded by the cost of the "moral hazard premium" or higher face value of interbank debt. In the general case, however, the Corollary may not hold and banks will then prefer to settle at the end of the day.

Net Settlement

An alternative means of limiting banks' leverage is to settle payments on a net basis. In the model environment, net settlement would be implemented as follows. Suppose that banks do not have the option of liquidating their portfolio at $t = 0$. Instead, after trading at $t = 0$, the payment system calculates each bank's net position vis-à-vis all other banks. Banks in a net debit or due-to position then transfer final goods to the payment system at $t = 1$, which in turn transfers these to the banks in a net credit or due-from position.

To see how net settlement can affect banks' incentives, suppose that interbank trading follows the "credit chain" pattern of Kiyotaki and Moore (1997), so that each bank n is a creditor of bank n+1 and a debtor of bank n-1 (mod N). This pattern of transactions is depicted in Figure 1. Each bank supplies an intermediate good to the next bank and takes delivery of an intermediate good from the preceding bank, so that by symmetry, each bank's net position vis-à-vis all other banks is zero after trading. In this particular case, banks have no incentive to take on excess levels of risk, since under net settlement, their leverage is reduced to zero. In other words, net settlement can limit the undesirable incentive effects of interbank debt, by giving "ex ante" priority to offsetting debt claims.[12] Such claims are automatically discharged under net settlement rules, eliminating the leverage associated with the exchange of debt claims and thereby the moral hazard that accompanies it.

In practice, net settlement may not work as well as in the Kiyotaki-Moore example, for a number of reasons. First, while the patterns of transactions among a group of banks may net out to zero over a longer period of time, on any given day not every bank will end up in a net position of exactly zero, so leverage cannot be completely eliminated. Second, since some banks will end up in a net debit position, there is always the possibility of default. And, because settlement takes place through a central counterparty (the payment system), the default of even a single net debtor necessarily affects the liquidity of entire payment system, and can make normal settlement impossible, i.e., contagion scenarios are possible. Hence, a complete analysis of a net settlement system should take into account these considerations. In particular, the analysis should incorporate mechanisms for either completing or suspending settlement when a net debtor defaults.

To incorporate these details into the analysis, consider a variant of the model where payments are not always offsetting. Suppose in particular that the total number of banks N is quite large, and that all banks possess the technology for final goods production, but that not all banks have the technology for producing intermediate goods. However, banks do not know in advance whether they will be able to produce intermediate goods. On any given trading day, only a fraction $p < 1$ of banks will be capable of producing intermediate goods that are useful in final goods production (these banks are each capable of producing $1/p$ intermediate goods). This pattern of transactions is depicted in

Figure 2 for the case where p=½. Before trading, each bank must determine the instantaneous variance of its portfolio σ^2.

Under this specification, all banks will have due-to positions of the same size (i.e., the face value B of the interbank debt claim), but only a fraction p of the banks will have offsetting due-from positions. Thus, a fraction $1-p$ of banks will be in a net debit position of B after trading, and some of these banks may default on their settlement obligation. To maintain tractability, I will assume that contagion does not occur, because the central bank is willing to guarantee the liquidity of the payment system in cases where banks default. In practical terms, such a guarantee could be implemented in a number of ways. The net settlement system could operate under an explicit central bank guarantee, as in the case of Canada's LVTS system.[13] Or the payment system could be operated as a gross settlement system, in which free, uncollateralized intraday credit is offered by the central bank. In either case, the central bank effectively becomes "creditor of last resort."

In determining the optimal values of B and σ^2 for this case, the typical bank must now take into account the fact that its trading obligations may or may not be offset. Hence the bank's contracting problem is now given by

$$\max_{B,\sigma^2} pV(\sigma^2)+(1-p)f\left(V(\sigma^2),B,\sigma^2\right) \tag{22}$$

subject to individual rationality constraint (8). If σ^2 is verifiable, then banks will choose $\sigma^2=\sigma_m^2$, just as under gross settlement. If σ^2 is not verifiable, then the incentives of the debtor must be taken into account during contracting.

The following proposition can now be shown:

Proposition 3. Suppose that the payment operates as net settlement system with a central bank guarantee of settlement, or as a gross settlement system with free, uncollateralized intraday credit. In addition, suppose that each bank's choice of σ^2 *is not verifiable by its intermediate good supplier or by the central bank. Then if the probability of payment off-set is p less than, but sufficiently close to unity, banks will choose the same portfolio and the same face value of debt as in the case where* σ^2 *is verifiable, i.e., banks will choose* $\sigma^2 = \sigma_m^2$ *and* $B = B_m$.

Proof: From (22), the derivative of the debtor's objective with respect to σ^2 is given by

$$pV' + (1-p)\left(f_V V' + f_{\sigma^2}\right) \qquad (23)$$

For $p < 1$ but sufficiently large, (23) becomes negative, implying that the debtor will always choose $\sigma^2 = \sigma_m^2$ and hence $B = B_m$.

Q.E.D.

Corollary to Proposition 3. Under the hypotheses of Proposition 3, if A1 holds then for a payment probability p greater than but sufficiently close to zero, banks will choose $\sigma^2 = \sigma_u^2$ *and* $B = B_u$.

Proof: Under *A1*, note that (23) is positive for *p*>0 but sufficiently small. The proof then follows from the proof of Proposition 1.

Q.E.D.

The Corollary establishes that under a netting system when interbank obligations are not perfectly offsetting, then the same type of incentive problems can arise as under gross settlement without DVP. However, Proposition 3 states that if the degree of offsetting is high enough, then outcomes under a net settlement system can approximate the first-best. A gross settlement system with a DVP requirement (or sufficiently cheap liquidity) can always do better in terms of lowering banks' incentives to default, but may be costlier than net settlement in a social sense if liquidity is sufficiently expensive.

3. GROSS SETTLEMENT WITH QUEUING

The foregoing section establishes that incentive problems can arise as a result of the lag between the time that an interbank payment obligation is created, and the time that it is settled. There are two main methods by which this incentive problem can be attacked. The first is to either eliminate the time lag through DVP or through some similar arrangement that encourages banks to settle sooner rather than later. This method is effective but will incur some liquidity costs. The second method is to employ either net settlement, or gross settlement with uncollateralized intraday credit. When interbank transactions are largely offsetting, the second method can in some cases eliminate the leverage which is the source of the incentive problem.

As discussed in the Introduction, recent trends in the implementation of large-value payment systems have emphasized the first method over the second. A number of large-value payment systems that formerly operated as net settlement systems have been converted to real-time gross settlement systems. Central banks have also become more reluctant to extend uncollateralized intraday credit over their RTGS systems, as awareness of the associated risks has increased.

The potential liquidity costs of collateralization or DVP have generated interest in the use of RTGS payment systems that incorporate a queuing facility. In an RTGS system with queuing, payment orders are entered into the system but held pending, usually until sufficient funds become available to settle a given payment. Some types of queuing systems combine RTGS with a limited notion of offset. In these systems, if a payment is input into the queue and is offset by a payment already in the queue, then the two payments can be settled with no need to transfer central bank funds. In practice the offset need not be exact and residual amounts of central bank funds will be transferred. More sophisticated versions of this type of system look for multilateral offsets between an input payment and payments already in the queue.

The appeal of queuing systems is that they may be able to economize on liquidity costs in much the same way as net settlement systems or RTGS systems with uncollateralized intraday credit, but at the same time avoid the drawbacks of the latter two types of systems. Specifically, the liquidity of a queuing system with matching does not depend on liquidity of a central counterparty, as in a net settlement system. Nor does the central bank incur explicit credit exposure, although some implicit credit exposure may result if the central bank feels compelled to bail out creditors when banks default, i.e., if some banks are deemed "too big to fail."

To examine the incentive effects of this type settlement systems that incorporate queuing, it is necessary to introduce a second round of trading into the model. Suppose now that there are three time periods, i.e., $t = 0, 1, 2$. Final good production takes place between $t = 1$ and $t = 2$. At the beginning of period $t = 0$, banks determine the instantaneous variance of their portfolios (final good production). Some banks are able to find the necessary intermediate goods for their final good production during the first round of trading at $t = 0$. Other banks have to wait until the second round of trading at $t = 1$ to find the necessary intermediate good. Still others may not be able to find the "right" intermediate good in either round of trading. Also, not all banks produce intermediate goods that are useful for final good production. As in the net settlement section above, banks do not know in advance whether their intermediate goods will be in demand or not.

Settlement takes place according to the following rules. Suppose that banks do not have the option of early ($t = 0$ or $t = 1$) liquidation of their portfolios. Instead, banks acquiring intermediate goods at $t = 0$ enter their payments into a queue. If these payments are offset in period $t = 1$, then the payment is considered settled. If not, the payment must be settled on a gross basis at $t = 2$. Let us now consider the effects of such a settlement system for two example economies, each with different patterns of trading.

Example 1. Queuing Replicates Net Settlement

Suppose that half of the banks (say the odd-numbered banks) acquire intermediate goods in the first trading round ($t = 0$) and that the other half of the banks (the even-numbered banks) acquire intermediate goods in the second round of trading ($t = 1$). Further suppose that odd-numbered banks buy from even-numbered banks and vice-versa. In this example, after two rounds of trading the net position of each bank is zero, as in the "credit chain" example for net settlement. This transaction pattern is depicted in Figure 3. In this case, there will be no (net) interbank obligation after trading at $t = 1$, and banks will choose their portfolios so as to maximize their expected value *V*, i.e., they will choose $\sigma^2 = \sigma_m^2$.

Example 2. Queuing Replicates Gross Settlement without DVP

In this example, some banks will obtain one unit of an intermediate good from one other bank as in the example above. Other banks will obtain one-half unit of an intermediate good from two other banks. Interbank obligations occur in "chains," where a chain is a group of banks of size *K*, and *K* is an even number that divides the total number of banks *N*. The following pattern of obligations occurs (see Figure 4):

Odd-numbered banks: Bank 1 acquires one intermediate good from Bank 2, Bank 3 acquires one good from Bank 4, … , Bank $K-1$ acquires one good from Bank *K*.

Even-numbered banks: Bank 2 acquires one-half unit of an intermediate good from Bank 1 and one-half unit from Bank 3, Bank 4 acquires one-half unit from Bank 3 and one-half unit from Bank 5, … , Bank $K-2$ acquires one-half unit from Bank $K-3$ and one-half unit from Bank $K-1$. Bank *K* is unable to find the right type of intermediate good to engage in final good production.

Suppose that odd-numbered banks acquire intermediate goods at $t=0$ and that even-numbered banks acquire intermediate goods at $t=1$. After the two rounds of trading, every bank will have acquired one unit of an intermediate good and will have also supplied one unit of an intermediate good, with the exception of Banks 1 and *K* in each chain. For sufficiently large chain sizes *K*, the probability of any bank being one of the endpoints in a chain is negligible. Hence, in the limit banks will allocate their portfolios under the assumption that they end up as an "interior" bank in a chain, i.e., under the assumption that they will not end up at either endpoint in a chain.

If the payment system were operated as a netting system, then every interior bank would have a net position of zero after trading, and would consequently have zero leverage. Under a queuing system, however, the due-to and due-from positions of interior banks cannot be offset since they do not match, even on a multilateral basis. Hence, each interior bank will have a (gross) settlement obligation of B_q, where B_q is the face value of the debt issued by the bank to its intermediate good supplier. Since the probability of offset is virtually zero for large *K*, then in the limit banks will choose their portfolios, and they will issue debt with the same face value as in the case of gross settlement without DVP. More precisely, for *K* sufficiently large σ_q^2 and B_q will be given by σ_u^2 and B_u, respectively.

Policy Implications of the Examples

The examples illustrate that a queuing system may or may not allow for the offset of obligations to the same extent as a net settlement system, or a gross settlement system with uncollateralized intraday credit. Example 2 shows that a queuing system cannot offset settlement obligations in a situation where (a) patterns of obligations vary across banks, and (b) settlement obligations of some banks are of large enough size so that bilateral offset of these obligations does not occur. In such cases, “intraday gridlock” can develop, with the undesirable side effect of increasing gross exposures at the end of the day. In the extreme case depicted in Example 2, there is no possibility of offset, implying that the payment system effectively operates as a gross settlement system where settlement is delayed until the end of the day.

In practice, the net benefit of implementing such a queuing system would depend on a number of factors. If liquidity were available at a low cost early in the day, then banks would voluntarily settle positions early (Corollary to Proposition 2) and intraday gridlock scenarios would not develop. Likewise, if patterns of payment obligations were usually offsetting to a large degree, a queuing system would provide much the same incentives as a net settlement system as in Example 1 above. On the other hand, if scenarios such as Example 2 were sufficiently likely, a queuing system would provide undesirable incentives to participating banks.

As a final note, I point out that intraday gridlock could be prevented if the payment system were to settle on a net basis at the end of the day, or if banks had access to free intraday credit from the central bank. Introduction of either of these two features might eliminate any rationale for queuing, however.

5. CONCLUSION

The analysis above considers the potential effects of rules for interbank settlement on banks' portfolio decisions. The lag between the time a payment obligation is created and the time it is settled can create incentives for banks to take on excessive risks (Proposition 1). Limiting the incentive for such "risk-shifting" should be an objective of all payment systems. In a gross settlement system, this incentive can be limited through the introduction of DVP or if banks' cost of holding liquid assets is sufficiently low (Proposition 2). In other cases, the costs imposed by DVP may outweigh the benefits provided in terms of limiting risk-shifting. A net settlement or a gross settlement system with free overdrafts can also limit risk-shifting if payments are sufficiently offsetting (Proposition 3). Likewise, a payment system which combines RTGS with queuing can constrain risk-shifting, but will sometimes be ineffective in cases where netting or RTGS with free overdrafts would work well (Examples 1 and 2 of Section 4).

Analysis of different modes of settlement is relevant for the case of Japanese payment institutions. In the near future, there will be a number of changes in the structure of BOJ-NET, the large-value payment system operated by the Bank of Japan. Currently, participants in the BOJ-NET system can settle transactions in either “designated-time settlement” mode (essentially multilateral net settlement with four settlements each day) or “real-time settlement” (RTGS without overdrafts) mode. Virtually all transactions are now settled in designated-time settlement mode. By the end of the year 2000, the Bank of Japan will abolish designated-time settlement, so that RTGS will be the only available mode of settlement. After this changeover occurs, banks will be able to run intraday overdraft positions, as long as these are fully collateralized. Intraday overdrafts will not be subject to interest charges or quantitative limits, and there will be no centralized queue for payments.[14]

Given current levels of interest rates in Japan, the near-term cost of a changeover to RTGS should be quite low. The most relevant result of the model for the near-term case would be the Corollary to Proposition 2, which suggests that payments will not be subject to strategic delay when the costs of liquidity are low. Over the longer term, however, Japanese interest rates are almost certain to rise above current levels, and the costs of collateralized intraday credit are bound to rise. In this case there will be a stronger incentive for banks to delay payments, as well as some renewed interest in features such as queuing, which attempt to lower banks’ liquidity costs.

The examples in Section 4 suggest that queuing schemes should be subject to careful investigation before they are implemented. In particular, queuing schemes which can cause significant increases banks’ end-of-day exposures may have the undesirable side effect of increasing banks' incentives to engage in risk-shifting behavior. The analysis suggests several alternative approaches: these include lowering the cost of collateralization for banks, and making greater use of DVP.

A closer examination of queuing systems would take into account a number of considerations that the analysis above abstracts from. These would include more realistic modeling of payment flows among banks, more sophisticated modeling of banks' default decisions, and a treatment of strategic interactions between banks and their depositors. These tasks are left for future research.

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NOTES

[1] For example, DeRoover (1948) records that medieval European banks settled on a net basis. Bagehot ([1873] 1991) and Cannon (1910) describe the operation of "clearing-house" (net settlement) systems for settling check payments in the 19th century U.K. and U.S. respectively. Even as recently as the early 1990s, most large-value transfer systems in developed countries settled on a net basis; see Bank for International Settlements (1993).

[2] See for example, Folkerts-Landau, Garber, and Schoenmaker (1996) for a discussion.

[3] For example, according to BIS statistics (Bank for International Settlements 1999), the average gross value of BOJ-NET (the large-value payment system operated by the Bank of Japan) transactions over three days roughly equals the annual nominal GDP of Japan. In the U.S. case, the average gross volume of six days' payments over CHIPS (the large-value payment system operated by the New York Clearing House Association) roughly equals U.S. nominal GDP.

[4] See the "Lamfalussy Report" of the Bank for International Settlements (1990). The Lamfalussy standards impose a number of requirements on net settlement systems. The most well-known requirement is that the system have access to sufficient liquidity to cover the net debit position of any single participant.

[5] For example, the (U.S.) Fedwire system charges banks interest on intraday overdrafts that exceed a bank's preset limit. See, for example, Federal Reserve Bank of New York (1995). The European Central Bank's Target system allows intraday overdrafts but requires these to be fully collateralized; see European Central Bank (1998). By the end of

the year 2000, BOJ-NET will be converted to a RTGS system whose design resembles that of Target in many respects. Upcoming changes in BOJ-NET are discussed below.

[6] In practice such claims may arise from depositors' transfers of their deposit claims, or from banks' trading for their own account. The level of abstraction in the model is such that it cannot distinguish between these types of transfers. When the trade represents a transfer of a deposit, in effect the bank is swapping one form of debt (a deposit) for another (an interbank claim), where the swap might or might not be contingent on settlement of the transfer. While such "debt swaps" do not imply a nominal increase in the debtor bank's leverage, de facto its leverage may increase, since in most countries the priority of depositors' claims is given special legal status, while the priority of interbank debt claims is often less secure. See Kahn and Roberds (1998) for a model of interbank settlement that incorporates the special status of depositors' claims.

[7] In practice, the structure of debt obligations could change in response to changes in the structure of the payment system. For example, a fairly stringent delivery-versus-payment or DVP constraint could cause banks to consolidate transactions or enter into netting agreements so as to minimize liquidity cost.

[8] In the payments literature, gross settlement is commonly referred to as "real-time gross settlement" or RTGS. Since there is only one trading round in the present environment, gross settlement is automatically "real-time."

[9] There is often some ambiguity concerning the exact meaning of the term "delivery versus settlement." Emmons (1997) discusses different forms of DVP systems. In Emmons' classification, the settlement procedure in this section is not a "DVP Model 1" system which requires simultaneous gross settlement of goods (securities) and money. However,

the settlement procedure of this section would qualify as a “DVP Model 2” system in which gross settlement of securities is followed by gross settlement in money.

[10] For convenience, this formulation of the contracting problem assigns all bargaining power to the debtor bank.

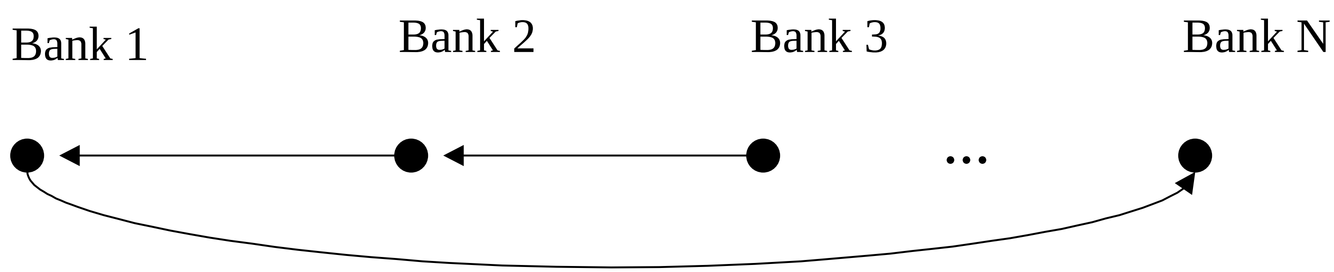
[11] For a discussion of the type of complications that can occur, see Prescott (1999). The contracting problem in Proposition 1 can be solved under weaker conditions than *A1*, but this would result in additional technical complexity while adding little in terms of the model’s policy implications.

[12] The priority of offsetting claims requires some legal sanction of the finality of the netting agreement. See the discussion in Emmons (1997).

[13] See Dingle (1998) on the structure of LVTS system.

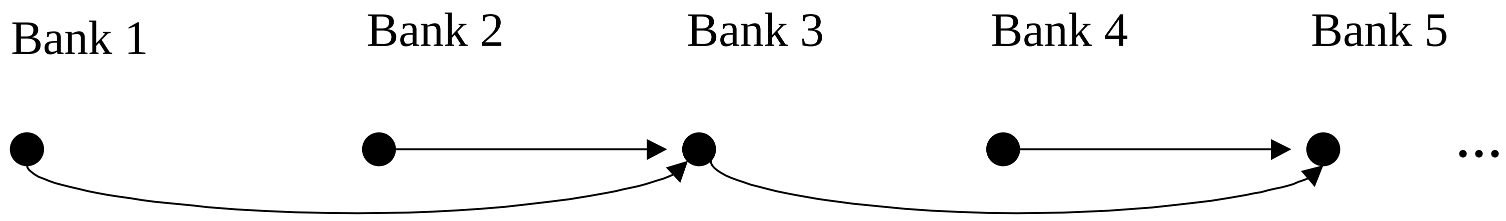
[14] See Matsushita (1997) and Bank of Japan (1997).

Figure 1: Kiyotaki - Wright Credit Chain



•Arrows indicate indebtedness

Figure 2: Partial Offset

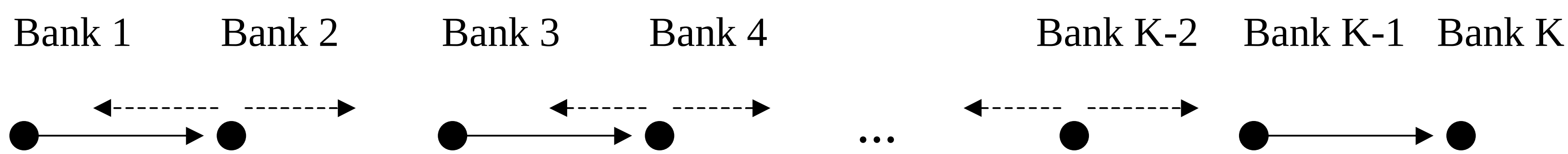


- Arrows indicate indebtedness
- Ex ante probability of offset p = 0.5

Figure 3: Queuing Replicates Net Settlement

•Arrows indicate indebtedness

Figure 4: Queuing Replicates Gross Settlement Without DVP



•A typical “chain” of size K is shown

•A solid arrow indicates indebtedness for one unit of an intermediate good

•A dotted arrow indicates indebtedness for one-half unit of an intermediate good