Real-Time Gross Settlement and the Costs of Immediacy

Charles M. Kahn and William Roberds

Federal Reserve Bank of Atlanta
Working Paper 98-21a
Revised November 1999

Abstract: Using a neoclassical monetary model, we investigate the welfare cost of a payment system that operates as a real-time gross settlement (RTGS) system. We illustrate how the cost of such systems does not ultimately derive from factors such as "payments gridlock" but instead from the credit constraints imposed by RTGS. We also investigate the welfare consequences of various approaches to the allocation of daylight credit by central banks. The two most popular approaches, collateralization and charging an administered intraday interest rate, are shown to be effective along some dimensions but flawed in others.

JEL classification: E42, G21, N20

Key words: payments, money, real-time gross settlement

The authors thank Scott Freeman, David Humphrey, David Marshall, Stacey Schreft, Bruce Smith, David Van Hoose, and seminar participants at Hitotsubashi University, the Hong Kong University of Science and Technology, the Clarence Tow Conference at the University of Iowa, the University of Texas, and the Federal Reserve Banks of Chicago, New York, and San Francisco for helpful discussions and comments. The views expressed here are those of the authors and not necessarily those of the Federal Reserve Bank of Atlanta or the Federal Reserve System. Any remaining errors are the authors' responsibility.

Please address questions regarding content to Charles M. Kahn, Department of Finance, University of Illinois, 217 David Kinley Hall, 1407 West Gregory Drive, Urbana, Illinois 61801, 217/333-2813, c-kahn@uiuc.edu; or William Roberds, Research Department, Federal Reserve Bank of Atlanta, 104 Marietta Street, NW, Atlanta, Georgia 30303-2713, 404/521-8970, 404/521-8956 (fax), william.roberds@atl.frb.org.

Real-Time Gross Settlement and the Costs of Immediacy

Large-value or wholesale payment systems are a vital component of all developed economies. The two large wholesale payments systems in the U.S., Fedwire and CHIPS, account for $2.6 trillion of transactions daily. Fedwire is used to transmit most large-value transactions in the U.S., including transactions associated with settling retail payment systems such as checks and credit cards, and also including settlement transactions for most financial markets. CHIPS is used primarily to settle the dollar legs of foreign exchange transactions.[1]

Recent years have seen a rapid expansion in the volume of wholesale payments world-wide. Since all wholesale payment systems settle on the books of central banks, this expansion has caused central banks to reexamine the advantages and disadvantages of the various types of arrangements for settlement. Central banks have become increasingly aware of the risk inherent in provision of subsidized credit, given the presence of moral hazard or asymmetric information. The response has been a general shift towards *real-time gross settlement* (RTGS) systems.[2] A real-time gross settlement system is a payment system in which all payments take the form of transfers of central bank funds from the account of paying bank to the receiving bank. (By contrast, under a *multilateral net settlement* system, payment messages are exchanged continuously, and participants' net positions vis-à-vis all other participants are settled on a periodic basis, usually at the close of business.)

In almost all RTGS systems, central banks provide intraday credit to participating banks. The terms for such credit vary from system to system, though recent concerns with credit risk have meant that in most cases, credit is only available in limited amounts or at some cost. In some systems, interest is charged for intraday credit, though at an administered rate rather than at a market rate. Collateral of various types may be required before credit is granted.

The argument in favor of central banks' provision of intraday credit in a RTGS system is that otherwise RTGS would impose undue costs on banks and on their customers.[3] The holding of liquid assets is costly to the participating banks. When they economize on these holdings, it limits the availability of reserves. In many RTGS systems, it is claimed, limited reserves cause delays in the processing of payments as banks wait to amass the reserves required to effect payments. Thus, a RTGS regime without intraday credit provision is often said to involve a loss of liquidity and immediacy.

The social balance between the costs and benefits of publicly provided intraday liquidity is, however, poorly understood. To obtain a better idea of the costs associated with real-time gross settlement, we develop a general equilibrium model of a RTGS payment system. In our model, liquidity constraints imposed by RTGS can delay trading and settlement. The costs of such delays, in turn, arise from the model's underlying preferences and technologies. We also use the model to examine the effects of various mechanisms for provision of intraday credit. Our analysis highlights the advantages and disadvantages of the two most common approaches by central banks to managing intraday credit, i.e., requiring full collateralization and charging interest. We also show how another types of policy, i.e., requiring only partial collateralization of intraday credit, is able to counteract the liquidity constraints imposed by RTGS and may thus offer another useful approach in this area.

I. Literature Review

Recent developments in large-value payment systems have generated a large body of research. A comprehensive literature review is presented in Angelini (1998). Below, we briefly review some papers whose subject or approach overlaps closely with ours.

Furfine and Stehm (1998) also consider the design of a RTGS payments system. In their setup, the central bank's intraday credit policy may incorporate pricing of intraday credit, quantity limits on credit, and either full or partial collateralization. Optimal credit policy balances the costs of stricter credit policies (gridlock and collateral costs) against the costs associated with more liberal credit policies (increased credit risk), where these costs are incorporated into reduced-form functions. The optimal credit policy varies with the relative weights ofeach type of cost.

Angelini (1998) shows that RTGS, when combined with the insufficient availability of intraday credit, can result in an interbank coordination problem. Liquidity constraints and uncertainty about incoming payment flows induce a form of payments "gridlock." Banks delay outgoing payments in the hope of reducing their liquidity demands by receiving early payments. Such delays lead to an inefficient aggregate increase in the precautionary demand for reserves. Imposing RTGS can thus impose liquidity costs and result in payment delay. A similar type of setup is analyzed by Kobayakawa (1997). In Kobayakawa's model, delay of payments is an equilibrium outcome when intraday credit is priced but not subject to a collateral requirement. Delays are avoided when intraday credit is collateralized, but collateralization imposes additional costs on banks. Hence, choice of intraday credit policy under RTGS involves a tradeoff between potential costs of delay and the costs of collateral.

The papers cited above each consider the design of an RTGS system within the context of static models of a banking system, in which the real return on money and on certain other types of assets is taken as exogenous. This feature must be seen as a limitation in calculating the true welfare cost associated with central banks' intraday credit policies. Since intraday expansion and contraction of a central bank's balance sheet amounts to a very high-frequency variation in monetary policy, we would expect prices to adjust in response to changes in the availability of intraday credit.

Possible consequences of allowing prices to vary over the short run are suggested by the analysis of Champ et al. (1996), who construct a monetary model of 19th century bank panics.[4] Banks in their model are subject to a seasonal (measured in months, not hours) pattern of fluctuations in deposit outflows. If banks have access to free seasonal ("intra-year") credit by virtue of their ability to print circulating notes, then nominal interest rates are constant, seasonal changes in the demand for notes are reflected in price changes, and the resulting equilibrium allocation is Pareto-optimal. When banks are credit-constrained by an inability to print notes, then nominal interest rates fluctuate seasonally, seasonal patterns in prices are reversed, real returns are distorted, delays in payments occur, and the resulting allocation is inefficient.

While the analysis of Champ et al. (1996) is specifically applied to 19th century institutions, recently a number of papers have adapted neoclassical models of money the analysis of contemporary payment systems.[5] In each of these models, restricting central bank credit within a "trading period" often leads to distortions and efficiency losses. Lacker (1997) explicitly models a second-best problem of setting intraday credit policy, given an inflationary overnight monetary policy. In Lacker's model, intraday credit policy matters because an RTGS requirement is imposed on banks during a part of the day when they lack full access to credit markets. In cases where the RTGS constraint binds, bank customers are in effect credit-constrained, causing them to suboptimally reallocate consumption from one day to the next. Intraday provision of central bank credit can partially reverse the effects of these credit constraints.

Similar results are obtained in a model developed by Freeman (1996b) and extended by Green (1997). In the Freeman-Green model, intraday credit constraints arise due to agents' patterns of spatial separation. The effects of these credit constraints can be completely reversed (in a model without risk) if the central bank provides free overdrafts (Freeman) or allows for net settlement by a private clearinghouse (Green).

Below, we develop a model that focuses on the intraday effects of RTGS-induced liquidity constraints. We divide each trading day into "morning" and "afternoon" segments, and then studying the effects of RTGS on intraday allocations. We examine a standard neoclassical monetary model in an environment that forces a sharp distinction between intraday and overnight trading. Since the model environment does not incorporate uncertainty, it can be constructed so that the imposition of real-time gross settlement can result in trading delays without payment gridlock or even queues. While gridlock and queues are potentially important problems for a payment system, their occurrence is not necessary for RTGS to result in welfare costs. Instead, we demonstrate such costs can arise simply from disturbances to intraday patterns of trade.

II. The Environment

Consider an overlapping generations environment where each generation is of constant size. Time is discrete and infinite, and there is no uncertainty. In order to analyze issues concerning intraday credit provision, time periods are divided into "mornings" (odd periods) and "afternoons" (even periods). Mornings and afternoons are classified as into trading "days." A new generation is born every day and lives for three periods—two afternoons and the morning in between, as depicted in Figure 1. Agents do not consume in the first period of their lives and do not produce in the last period. An agent's utility is described by the function

$$U(1-l_1)+U(1-l_2)+V(c_2)+\alpha V(c_3) \quad (1)$$

Above, *c* denotes consumption and *l* denotes labor in the indicated period of the agent's life. The functions *U* and *V* are increasing, concave, twice continuously differentiable, and have sufficient curvature so that indifference curves do not cross the axes. The parameter $\alpha \in (0,1)$ is a discount factor that reflects agents' inherent preference for morning consumption.

Agents are endowed with one unit of labor in the first two periods of life. One unit of labor in any period produces one unit of consumption in the same period. To give agents an incentive to trade, there are standard taboos against consuming one's own production. Note that agents can only produce afternoon goods while young, but only wish to consume afternoon goods when old. During the second afternoon of life, an old agent is willing to consume goods produced by any young agent, and the old agent views all such goods as perfect substitutes. In the mornings, the agent's preferences are more specific. We assume that each generation is divided into *N* groups of equal size, where *N* is at least three. Each agent of group *n* wishes to consume only "morning goods" of the type produced by group *n*+1 (mod *N*). The technology for trading such that agents can only purchase one type of commodity and sell one type of commodity during the morning. Imposing this restriction precludes arrangements in which agents achieve settlement by buying and selling all types of goods. The purchase and sale take place simultaneously, so there is no uncertainty concerning the timing of agents' trades. This is more drastic than necessary, but it is useful for expositional purposes, since it will make clear that "gridlock" is not necessary for frictions to arise under RTGS.

Morning goods can also be transformed into afternoon goods using a costless intraday storage technology. In order to focus our analysis on intraday effects, we assume that afternoon goods cannot be stored for the next morning. In other words, agents can postpone delivery of a good from morning to afternoon without physical storage costs, but delivery cannot be postponed until the following day.

II.A. Walrasian equilibrium

To establish a benchmark case, we describe an efficient steady-state allocation in the economy. We do this by calculating the steady-state equilibrium allocation of a Walrasian economy, in which some of the trading frictions described above are relaxed (i.e., imagine that agents can produce and consume during the same afternoon, and there are double coincidences during mornings). In this case, the economy effectively becomes a sequence of static economies.

If there were no possibility of intraday storage, then the unique Walrasian steady-state equilibrium is found by maximizing the agents' utility (1) subject to the following budget constraint:[6]

$$p_2 c_2 + p_3 c_3 \le w_1 l_1 + w_2 l_2 \tag{2}$$

where p and w represent the price of consumption and labor, respectively. First-order conditions are

$$U'(1-l_1)/w_1 = U'(1-l_2)/w_2 = V'(c_2)/p_2 = \alpha V'(c_3)/p_3 \tag{3}$$

The production function requires that

$$w_2 = p_2 \tag{4}$$

$$w_1 = p_3 \tag{5}$$

The market clearing conditions are

$$l_2 = c_2 \tag{6}$$

$$l_1 = c_3 \tag{7}$$

Substituting (4)-(5) into first-order conditions (3) we obtain

$$\frac{U'(1-l_1)}{\alpha V'(c_3)} = 1 = \frac{U'(1-l_2)}{V'(c_2)} \tag{8}$$

Substituting market-clearing conditions (6)-(7) into (8) yields $c_2 > c_3$, which from (3) implies $p_2 > p_3$.

Now we return to the case where intraday storage is allowed. Then in Walrasian equilibrium, conditions (2) and (3) are unchanged and the market clearing conditions become

$$p_2 \geq p_3 \tag{9}$$

$$c_2 \leq l_2 \tag{10}$$

with complementary slackness, and

$$c_2 + c_3 \leq l_1 + l_2 \tag{11}$$

The intuition for condition (9) is no arbitrage.

Recall that $0 < \alpha < 1$, so that there is an inherent preference for consumption of morning goods. Thus, market-clearing condition (10) will bind, and conditions (10) and (11) reduce to (6) and (7). Hence equation (8) holds in the case with storage, implying:

Lemma 1. In the first-best allocation, the consumption of the morning good exceeds the consumption of the afternoon good, i.e.,

$$c_2^* > c_3^* \tag{12}$$

The shadow price of the morning good also exceeds the shadow price of the afternoon good, i.e.,

$$V'(c_2^*) > \alpha V'(c_3^*) \tag{13}$$

III. Exchange under RTGS

Suppose that the trade frictions described above are now in effect, and further suppose the existence of a constant per capita amount of outside fiat money, denoted *M*. For the moment, suppose that money is the only outside claim on the economy. In this environment, the banking system exists merely as a device for clearing and settling payments. Money exists only in the form of electronic claims on a central bank and all payments are made via the central bank's clearinghouse. The clearinghouse operates under a "pure" form of RTGS, in which all payments made via the clearinghouse must be in the form of (electronic) transfers of outside money, and the central bank grants no credit to its members. In the tradition of the "monetary" literature on payments arrangements (see Section 1) we also assume that goods and money must change hands simultaneously. And, since our goal is to consider policy environments where net settlement is excluded in principle, agents are also prohibited from netting exchanges of goods among themselves.[7] Thus, for labor in period 1 the agent receives fiat money which he may spend in period 2 (or store until period 3). For labor in period 2 he receives fiat money which he may spend in period 3.

Under RTGS each agent's budget set is constrained as

$$M \leq w_1 l_1 \tag{14}$$

$$p_2 c_2 \leq M \tag{15}$$

$$p_2 c_2 + p_3 c_3 \leq w_2 l_2 + M \tag{16}$$

Note that constraint (15), the RTGS constraint, serves as an intraday cash-in-advance constraint that limits the agent's purchases of the morning good c_2 up to the value of the afternoon good l_1 that he produced the previous afternoon. If (15) binds, then after substitution from (4)-(5) agents' first-order conditions reduce to

$$\frac{V'(c_2)}{U'(1-l_1)} = \frac{p_2}{p_3} = \frac{U'(1-l_2)}{\alpha V'(c_3)} \tag{17}$$

It is easy to show that the first-best allocation of Section I cannot obtain under RTGS. Constraints (14) and (15) imply that amount of funds available for the purchase of the morning good cannot exceed earnings from the previous afternoon, that is

$$p_2 c_2 \leq w_1 l_1 \tag{18}$$

In steady-state equilibrium, earnings on afternoon production is less than or equal to expenditures on afternoon goods, i.e.,

$$w_1 l_1 \leq p_3 c_3 \tag{19}$$

It follows that in equilibrium, expenditures on morning goods cannot exceed expenditures on afternoon goods, i.e.,

$$p_2 c_2 \leq p_3 c_3 \tag{20}$$

Note that (20) cannot hold for $(c_2, c_3) = (c_2^*, c_3^*)$, since from Lemma 1, the first-best allocation requires $c_2^* > c_3^*$ and $p_2 > p_3$. Hence the first-best outcome is not attainable under RTGS with a constant money stock and no intraday credit. More specifically, we can show:

Proposition 1. Suppose that there is a constant stock of money, and that the clearinghouse operates under RTGS with no intraday credit. Then the resulting steady-state equilibrium allocation must be inefficient, and in particular either (1) the equilibrium consumption of the morning good must be less than the equilibrium consumption of the afternoon good, or (2) the prices of the two goods are equal.

Proof: Non-satiation implies that constraint (14) must bind. From the discussion above, the Walrasian allocation cannot be attained under RTGS, implying that (15) binds and hence that (18) binds. Suppose that $p_2 > p_3$. It follows that (19) binds, and that (20) holds as an equality, i.e., $p_2 c_2 = p_3 c_3$, which then implies $c_2 < c_3$.

Q.E.D.

In the present environment, the costs of RTGS are manifested in agents' substitution away from the more desirable (morning) good and toward the less desirable (afternoon) good, relative to the first-best case. At the beginning of the trading day, agents anticipate incoming payments from sale of their own morning goods, but cannot borrow against this future income, which discourages consumption of the morning good. An inefficient allocation results.

The impact of the RTGS constraint is also reflected in the cycle of real interest rates over the trading day. From Lemma 1, the first-best allocation requires that the net real return on money be positive overnight (i.e., $(p_2 / p_3) - 1 > 0$) and negative from morning to afternoon. In contrast to the results of Champ et al. (1996), no-arbitrage condition (9) guarantees that this qualitative pattern of real interest rates is sometimes preserved under RTGS, i.e., for the case where $p_2 > p_3$. However, in this case the quantitative effect of the RTGS constraint is to dampen the cycle of real rates over the trading day. For the case where $p_2 = p_3$, real rates are constant and equal to zero over the trading day. This case also exhibits "queueing" of transactions over the day, in the sense that some goods produced in the morning are not delivered until the afternoon. Queuing is not necessary for RTGS to result in a welfare loss, however.

Since Proposition 1 holds in a stationary economy with a constant money stock, it should be clear the inefficiency of RTGS does not depend on inflationary (overnight) monetary policy. Instead, the inefficiency results from a failure of the central bank to accommodate the economy's "seasonal" demand for central bank money. Similar results have been shown in Freeman (1996b), Green (1997), and Lacker (1997). What we have done is to show that the effects of RTGS can also be manifested in "delay," i.e., in disruptions of intraday trading patterns.

III.A. Interest-free daylight overdrafts

The traditional policy of central banks in many countries has been to allow banks access to free intraday credit, often in the form of overdrafts on their accounts with the central bank. Formally, we can model this policy in a world with a constant money stock by modifying constraints (15) and (16) to allow for overdrafts:

$$p_2 c_2 \leq M + O \tag{21}$$

$$p_2 c_2 + p_3 c_3 \leq w_2 l_2 + (M + O) - O = w_2 l_2 + M \tag{22}$$

where O represents the daylight overdraft. Thus, daylight overdrafts effectively loosen the cash-in-advance constraint (15). If credit is only available up to a fixed amount, then the equilibrium allocation depends on the amount of credit available.

Suppose that a sufficiently small amount of intraday credit is available, so that constraint (21) binds. Then first-order conditions reduce to

$$\frac{(1+\omega)V'(c_2)}{\alpha\omega V'(c_3) + U'(1-l_1)} = \frac{p_2}{p_3} = \frac{U'(1-l_2)}{\alpha V'(c_3)} \tag{23}$$

where ω denotes the overdraft-to-money ratio, i.e., $\omega = O / M$. We can now show:

Proposition 2. If free daylight overdrafts are limited to an amount $O \geq \omega^* M$ *, where*

$$\omega^* \equiv \left(\frac{V'(c_2^*)c_2^*}{\alpha V'(c_3^*)c_3^*} - 1 \right) \tag{24}$$

then the first-best allocation obtains under RTGS.

Proof: The budget constraint for the afternoon good (14) requires, after substituting conditions (5) and (7)

$$p_3 = M / c_3 \tag{25}$$

From Lemma 1, in the Walrasian economy it must hold that

$$p_2 / p_3 = V'(c_2^*) / \alpha V'(c_3^*) \tag{26}$$

Hence, if the first-best outcome is feasible, then it must be the case that purchases of c_2^* can be financed by daylight overdrafts. This requires, from budget constraint (21)

$$p_2 c_2^* = \frac{p_2}{p_3}(p_3 c_2^*) = \left(\frac{V'(c_2^*)}{\alpha V'(c_3^*)}\right)\left(\frac{M c_2^*}{c_3^*}\right) = \left(\frac{V'(c_2^*) c_2^*}{\alpha V'(c_3^*) c_3^*}\right) M \le M + O \tag{27}$$

which is equivalent to $(1+\omega^*)O \le (1+\omega)O$, which is evidently satisfied for $\omega \le \omega^*$. Hence the first-best outcome is feasible for $\omega = \omega^*$. It is then straightforward to show that first-order conditions (23) are satisfied for $(c_2, c_3) = (c_2^*, c_3^*)$, when $\omega = \omega^*$ and the relative price of morning goods is given by (26).

Q.E.D.

Thus, free intraday credit allows payment system participants to overcome the credit constraints imposed by RTGS, by allowing them to borrow central bank funds against anticipated payment inflows. In real-world payment systems such flows can be uncertain, however, so granting intraday credit could expose a central bank to unacceptable levels of credit risk.

IV. Collateralized Intraday Credit

One means by which a central bank could limit its intraday exposure would be to require collateral in return for access to daylight credit. Below, we analyze policies of this type, where intraday credit is collateralized by government bonds.[8]

We introduce bonds via a standard government budget constraint. Let B_t denote the nominal stock of government bonds as of the afternoon of *day* (not period) *t*. For analytical convenience, the entire government debt consists of bonds with a maturity of one day. Bonds may be purchased during the afternoon and mature the following afternoon. Although bonds bear interest, they do not necessarily dominate money as they cannot be used as a settlement medium before maturity.[9]

The government inherits an initial stock of government debt B_t, and pays this off via money creation. For simplicity, we assume that the government has no current expenditures or any other source of revenue, and that the central bank inflates the money stock at a constant rate μ per day. Letting i denote the nominal interest rate, the government budget constraint is given by

$$B_t = (1+i)B_{t-1} - (M_t - M_{t-1}) \tag{28}$$

Solving (28) forward reveals that the government's budget is balanced in a present-value sense as long as

$$\beta = \frac{\mu}{i-\mu} \tag{29}$$

where β represents the steady-state ratio of debt to money B/M. We require that $\beta > 0$, meaning that the government is indebted to the private sector and not vice versa.[10]

IV.A. Full collateralization

Suppose now that agents can run intraday overdrafts on their reserve accounts, but that each agent's overdraft is fully collateralized by his bond holdings. Formally, we require $O \leq \kappa(1+i)B$, where $\kappa \in [0,1)$ is a policy parameter that is set by the central bank. Under such a policy, an agent's budget set is constrained as

$$M + B \leq w_1 l_1 \tag{30}$$

$$p_2 c_2 \leq M + O \tag{31}$$

$$p_2 c_2 + p_3 c_3 \leq w_2 l_2 + M + (1+i)B \tag{32}$$

In the absence of a legal reserve requirement $\kappa(1+i)$ must be less than unity (i.e., the central bank must impose a “haircut” on posted collateral) in order for money not to be dominated by bonds.[11] Under full collateralization, it is straightforward to show:

Proposition 3. Suppose the clearinghouse operates under RTGS, with intraday credit available on a fully collateralized basis with $0 < \kappa(1+i) < 1$. *Then any steady-state equilibrium allocation must be inefficient.*

Proof: Constraint (31), together with the collateral requirement, implies

$$p_2 c_2 \leq M + \kappa(1+i)B < M + (1+i)B \tag{33}$$

In steady state, the daily rate of increase in prices and in the stock of outside assets is given by the inflation rate μ. Hence

$$M + (1+i)B = (1+\mu)(M + B) \tag{34}$$

which from (33) and (30) implies

$$p_2 c_2 < M + B \leq w_1 l_1 \tag{35}$$

As in the proof of Proposition 1, this in turn implies

$$p_2 c_2 < p_3 c_3 \tag{36}$$

The proposition follows since absence of arbitrage requires $p_2 \geq p_3$ and efficiency requires $c_2 > c_3$.

Q.E.D.

Proposition 3 shows that an RTGS regime of overdrafts with full collateralization causes agents to face much the same difficulty as under RTGS without overdrafts. That is, agents are credit constrained because they are unable to obtain full credit against anticipated inflows of funds. Hence, a regime of RTGS with fully collateralized overdrafts results in an inefficient allocation.

In policy discussions, the costs of collateralized intraday credit are often associated with the opportunity costs of holding government bonds as opposed to other types of assets.[12] Proposition 3 shows that such opportunity costs need not exist in order for a full collateralization requirement to impose costs.

Finally, we note that the "haircut" imposed by the central bank on bonds posted as collateral for overdrafts may be expressed in percentage terms as a $100(\kappa^{-1}-1)$ percent haircut on the face value of the collateral. The requirement that $\kappa(1+i)$ be less than unity is equivalent to a requirement that the haircut percentage be greater than the overnight nominal interest rate i. Since agents are credit-constrained for all fractional values of $\kappa > i$, an efficient allocation would not occur even in the limiting case.

IV.B. Partial collateralization

We now consider a regime in which intraday credit is only partially collateralized. That is, the central bank is willing allow overdrafts of reserve accounts up to some multiple of bonds deposited with the central bank. Formally, this is done by allowing the parameter κ to exceed unity. In this case, money is dominated by bonds, so that agents must be required to hold money in order for the price level to be determinate. To this end, we impose a legal reserve requirement, which forces all agents to hold money in a fixed ratio to their bond holdings. Present-value budget balance requires that in steady state, the required reserve ratio equal the initial ratio of money to bonds, i.e., $1/\beta$. The reserve requirement can be written as an additional (binding) constraint on the agent's budget set, i.e.,

$$B = \beta M \tag{37}$$

Thus, under partial collateralization, agents seek to maximize their utility (1), subject to budget constraints (30)-(32) and reserve requirement (37). This is really the same problem as in Section III.A. above. To see this define $\underline{M} = (1+\beta)M = M + B$ and rewrite (30)-(32) as

$$M + B \le w_1 l_1 \Leftrightarrow \underline{M} \le w_1 l \tag{38}$$

$$\begin{aligned} &p_2 c_2 \le M + O = (1+\mu)(1+\beta)M + (1+\mu)\underline{O} \\ &\Leftrightarrow \\ &p_2 c_2 \le \underline{M} + \underline{O} \end{aligned} \tag{39}$$

$$\begin{aligned} &p_2 c_2 + p_3 c_3 \le w_2 l_2 + (1+\mu)(1+\beta)M \\ &\Leftrightarrow \\ &p_2 c_2 + p_3 c_3 \le w_2 l_2 + \underline{M} \end{aligned} \tag{40}$$

where the transformed overdraft $\underline{O} = \left(O - (1+i)B\right)/(1+\mu)$ and is subject to the collateral constraint

$$O \le \kappa(1+i)B \Leftrightarrow \underline{O} \le \frac{(\kappa-1)(1+i)\beta}{(1+\mu)(1+\beta)}\underline{M} \tag{41}$$

By choosing the right combination of limits on intraday credit κ and monetary policy μ, the central bank can ensure the first-best outcome.

Proposition 4. Under RTGS with partial collateralization, the first-best outcome obtains if the central bank sets the inflation rate μ and the collateralization requirement κ to satisfy

$$\kappa \ge 1 + \frac{(1+\beta)(1+\mu)\omega^*}{\beta + (1+\beta)\mu} > 1 \tag{42}$$

where ω^* is given in (24).

Proof: Constraints (38)-(40) clearly match up with (14), (21), and (22), so the agents' problem is the same as analyzed in Section III.A. From Proposition 2, the first-best allocation obtains when $(\underline{M} + \underline{O})/\underline{M} \ge 1 + \omega^*$. From (41), this occurs when

$$\frac{(\kappa-1)(1+i)\beta}{(1+\beta)(1+\mu)} \geq \omega^{*} \tag{43}$$

Substituting the budget-balance condition (29) in (43) and solving for κ yields (42).

Q.E.D.

Proposition 4 shows that partial collateralization of intraday credit is compatible with efficiency. Attainment of the first-best outcome requires coordination in the setting of intraday credit policy (i.e., in the setting of collateral requirements) and the setting of more traditional "overnight" policies (i.e., the legal reserve requirement and the growth rate of the money stock). Condition (42) can be expressed in terms of the nominal interest rate i to yield

$$\kappa \geq 1+\left(\frac{1}{\beta(1+i)}+1\right)\omega^{*} \tag{44}$$

According to (44), efficiency requires a more generous collateralization requirement (a higher κ) for lower levels of the nominal interest rate and for lower levels of government debt.

At first glance, Proposition (4) might appear to offer the central bank a "free lunch." That is, a partial collateralization requirement satisfying (42) appears to offer the central bank an opportunity to reduce its exposure to payment system participants without simultaneously imposing liquidity costs. This cannot be the case, however, since the real value of the intraday credit extended, i.e., the value of the agent's morning consumption minus the value of his earnings from the previous afternoon, is the same in Proposition 4 as in Proposition 2. Partial collateralization does offer the central bank an additional amount of flexibility, i.e., if the central banker chooses a collateral requirement κ greater than unity but not satisfying (42), the welfare loss is reduced, relative to full collateralization, while the exposure of the central bank is reduced, relative to a policy of free daylight overdrafts.

V. Paying Interest on Central Bank Funds Held Overnight

Another possible policy response to the liquidity problems posed by RTGS would be for the central bank to augment agents' nominal income by paying interest on reserves held overnight. Suppose the central bank denies payment system participants access to intraday credit, but is willing to pay an interest rate $\underline{i}$ on central bank funds held overnight. To maintain the distinction between money and bonds in the absence of a reserve requirement, $\underline{i}$ would have to be less than the market rate on government debt *i.*[13] Interest payments on bonds and money are financed by money creation, so that government budget constraint (28) is replaced by

$$B_t = (1+i)B_{t-1} - \left(M_t - (1+\underline{i})M_{t-1}\right) \tag{45}$$

Steady-state budget balance requires that $\mu > \underline{i}$ and that the bonds-to-money ratio be given by

$$\beta = \frac{\mu - \underline{i}}{i - \mu} \tag{46}$$

In this case, budget constraint (14) is replaced by (30) and constraints (31)-(32) become:

$$p_2 c_2 \le (1+\underline{i})M \tag{47}$$

$$p_2 c_2 + p_3 c_3 \le w_2 l_2 + (1+\underline{i})M + (1+i)B \tag{48}$$

Formally, we can show:

Proposition 5. If the central bank pays an interest rate on reserves less than the inflation rate, then under RTGS without intraday credit the resulting equilibrium allocation must be inefficient.

Proof: Follows exactly the steps in the proof of Proposition 3, and is omitted.

Current U.S. policy does not allow for payment of interest on reserves. By making aggressive use of "sweeps" technology, however, banks have been able to substitute funds in interest-bearing Fed clearing accounts for funds in non-interest-bearing reserve accounts.[14] The effect has been “as if” these banks had received interest on part of their reserve accounts. Proposition 5 shows that such changes cannot completely undo the effects of intraday liquidity constraints.

VI. Charging Interest on Daylight Overdrafts

In the U.S., efforts to limit the Fed’s intraday credit exposure have emphasized charging an administered interest rate (or “fees”) for daylight overdrafts rather than collateralization.[15] In this section we consider the effects of such policies. Suppose that the central bank charges an interest rate of τ or fees of τO on morning overdrafts of O, and that the fees incurred on a given day are payable by the close of business (in the afternoon). Under such a regime, budget constraints for the agent’s problem are given by equation (30), together with the constraints

$$p_2 c_2 \leq M + O \tag{49}$$

$$p_2 c_2 + p_3 c_3 \leq w_2 l_2 + M + (1+i)B - \tau O \tag{50}$$

We will analyze the case where the interest rate on intraday overdrafts does not exceed the nominal interest rate on bonds, and where the legal reserve requirement (37) is in force. Note that if the interest rate on intraday overdrafts exceeds the interest rate on bonds, then overdrafts will never be used, since using overdrafts would be dominated by holding additional money balances. In practice, the interest rate on overdrafts (currently 27 basis points at an annual rate in the U.S.) is well below the interest rate on bonds. In the model, such a situation would cause money to be dominated by bonds in the absence of a legal reserve requirement.

Interest paid on daylight overdrafts is used to pay off the government debt. The appropriate steady-state budget balance condition becomes

$$\beta = \frac{\mu M + \tau O}{(i-\mu)M} \tag{51}$$

If there is no intraday storage in equilibrium, so that $p_2 > p_3$, then first-order conditions reduce to (in the case of positive overdrafts)

$$\frac{U'(1-l_2)}{\alpha V'(c_3)} = \frac{p_2}{p_3} \tag{52}$$

$$\frac{V'(c_2)}{U'(1-l_2)} = (1+\tau) \tag{53}$$

$$\frac{U'(1-l_1)}{\alpha V'(c_3)} = \left(1 + \frac{(1+\omega)\tau}{(1+\beta)(1+\mu)}\right) \tag{54}$$

From (54) it is clear that for each intraday interest rate τ there are a large number of possible equilibria, each indexed by the overdraft-to-money ratio ω. We can also show:

Proposition 6. Suppose that RTGS is in effect and that the central bank makes intraday credit freely available at a fixed interest rate $\tau > 0$. *Then the resulting equilibrium allocation is inefficient, but approaches the efficient allocation as* $\tau \downarrow 0$.

Proof: If $p_2 = p_3$ in equilibrium, then by Lemma 1 this is inconsistent with the first-best allocation. So suppose that $p_2 > p_3$. In this case, comparing (53) and (54) with (8) yields $c_2 < c_2^*$ and $c_3 > c_3^*$ for positive τ. Driving $\tau \downarrow 0$ causes (53) and (54) to approach (8).

Q.E.D.

Thus, the first-best allocation is unattainable under a policy of charging fees on daylight credit, but is approximately attainable for small values of the intraday interest rate. Of course, as the interest rate decreases, the central bank's exposure is likely to increase.[16]

VII. Conclusions

Above, we have presented a general equilibrium model of a payment system that operates under real-time gross settlement, in which the liquidity constraints imposed by RTGS result in settlement delays. Under "pure" RTGS, the resulting equilibrium allocation is inefficient, even though there is no uncertainty and no gridlock associated with settlement (Proposition 1). Instead, the inefficiency of RTGS stems from its implicit credit constraints. Granting payment system participants access to intraday credit from the central bank eases the effects of these credit constraints (Proposition 2), but may also result in unacceptably large intraday exposures on the part of the central bank.

Policy responses to this problem have generally stressed either (1) full collateralization of overdraft positions, or (2) charging interest on daylight credit. The analysis above suggests that while there is some merit in both types of policies, both are also flawed along some dimension. Allowing intraday credit only under full collateralization eliminates the daylight exposure of the central bank, and but cannot completely eliminate the effects of liquidity constraints imposed by RTGS (Proposition 3). Likewise, a policy of paying interest on reserves cannot undo these liquidity constraints (Proposition 5). Interest rates on daylight overdrafts can be adjusted to improve efficiency, but will simultaneously affect the central bank's intraday exposure (Proposition 6).

Our analysis does point to an approach that merits further investigation. A policy of partial collateralization of intraday credit, which when combined with the "right" choice of monetary policy, can allow a central bank to trade off the effects of liquidity constraints against intraday exposure (Proposition 4). Partial collateralization has been an important component of central banks' regulation of payment networks that settle on a net basis, but has not been extensively discussed in reference to RTGS systems.[17]

These conclusions are obviously tentative, since the analysis above abstracts from a number of important aspects of real-world payment systems. For example, uncertainty regarding payment flows and greater heterogeneity of payment system participants could work against the effectiveness of collateral requirements, unless these could be adjusted dynamically to match market conditions. On the other hand, the presence of credit risk and moral hazard might work against a system based on charging intraday interest, since relatively unfettered access to central bank credit could have negative incentive effects. The presence of other distorting taxes (i.e., other than the inflation tax on overnight central bank funds) might argue for higher intraday rates. Finally, the welfare calculations would be considerably complicated if intraday credit were also available over private payment networks.

Appendix: General Characterization of Efficient Allocations

In general, any sequence of productions and consumptions

$$\{(l_{1i}, l_{2i}, c_{2i}, c_{3i})\}_{i=1,2,3,\ldots} \tag{54}$$

(where *i* refers to the generation) is efficient if it has the following properties:

$$l_{1i} = 0 \tag{55}$$

and for all *i*

$$U'(1 - l_{2i}) = V'(c_{2i}) \tag{56}$$

$$l_{2i} \geq c_{2i} \text{ and } V'(c_{2i}) \geq \alpha V'(c_{3i}) \tag{57}$$

$$l_{1i+1} + l_{2i} = c_{2i} + c_{3i} \tag{58}$$

To each efficient allocation corresponds a sequence of prices $\{(w_{1i}, w_{2i}, p_{2i}, p_{3i})\}$

$$w_{2i} = p_{2i} \tag{59}$$

$$l_{2i} \geq c_{2i} \text{ and } p_{2i} \geq p_{3i} \tag{60}$$

(with complementary slackness)

$$l_{1i} + l_{2i} = c_{2i} + c_{3i} \tag{61}$$

In the general case, the condition guaranteeing that $l_{2i} = c_{2i}$ is binding is now more complicated, since it involves the relative welfare weights placed on the consecutive generations. However, the basic message is unaffected.

References

Angelini, P., 1998, "An Analysis of Competitive Externalities in Gross Settlement Systems." *Journal of Banking and Finance* 22: 1-18.

Bank for International Settlements, 1990, *Report of the Committee on Interbank Netting Schemes of the Central Banks of the Group of Ten Countries*, Basle.

Bank for International Settlements, 1993, *Payment Systems in the Group of Ten Countries*, Basel.

Bank for International Settlements, 1997, *Real-Time Gross Settlement Systems*, Basle.

Bank for International Settlements, 1998, *Statistics on Payment Systems in the Group of Ten Countries*, Basle.

Bank of Japan. "The Framework for Restructuring the BOJ-NET Funds Transfer System." *Bank of Japan Quarterly Bulletin* (August, 1997): 101-4.

Borio, Claude E.V. *The Implementation of Monetary Policy in Industrial Countries: A Survey*. Basel: Bank for International Settlements.

Champ, B., B. Smith, and S. Williamson, 1996, "Currency Elasticity and Banking Panics: Theory and Evidence." *Canadian Journal of Economics* 29: 828-64.

Emmons, W.R., 1997, "Recent Developments in Wholesale Payments Systems." Federal Reserve Bank of St. Louis *Review* 79 (November/December): 23-43.

European Central Bank, 1998, *Third Progress Report on the TARGET Project*, Frankfurt.

Evanoff, D.D., 1989, "Daylight overdrafts: Rationale and Risks." Federal Reserve Bank of Chicago *Economic Perspectives* 12: 18-29.

Folkerts-Landau, D., P. Garber, and D. Schoenmaker, 1996, "The Reform of Wholesale Payment Systems and its Impact on Financial Markets." Group of Thirty, Occasional Paper 51.

Freeman, S., 1996a, "Clearinghouse Banks and Banknote Over-Issue." *Journal of Monetary Economics* 38: 101-15.

Freeman, S., 1996b, "The Payments System, Liquidity, and Rediscounting." *American Economic Review* 86: 1126-38.

Freeman, S., 1999, "Rediscounting under Aggregate Risk." *Journal of Monetary Economics* 43: 197-216.

Furfine, C. and Stehm, C., 1998, "Analyzing Alternative Intraday Credit Policies in Real-Time Gross Settlement Systems." *Journal of Money, Credit, and Banking*, forthcoming.

Green, E., 1997, "Money and Debt in the Structure of Payments." Bank of Japan *Monetary and Economic Studies* 15: 63-87.

Hancock, D., and J.A. Wilcox, 1996, "Intraday Management of Bank Reserves: The Effects of Caps and Fees on Daylight Overdrafts," *Journal of Money, Credit, and Banking* 28: 870-908.

Kahn, C.M. and W. Roberds, 1998, "Payment System Settlement and Bank Incentives." *Review of Financial Studies*, 11: 845-70.

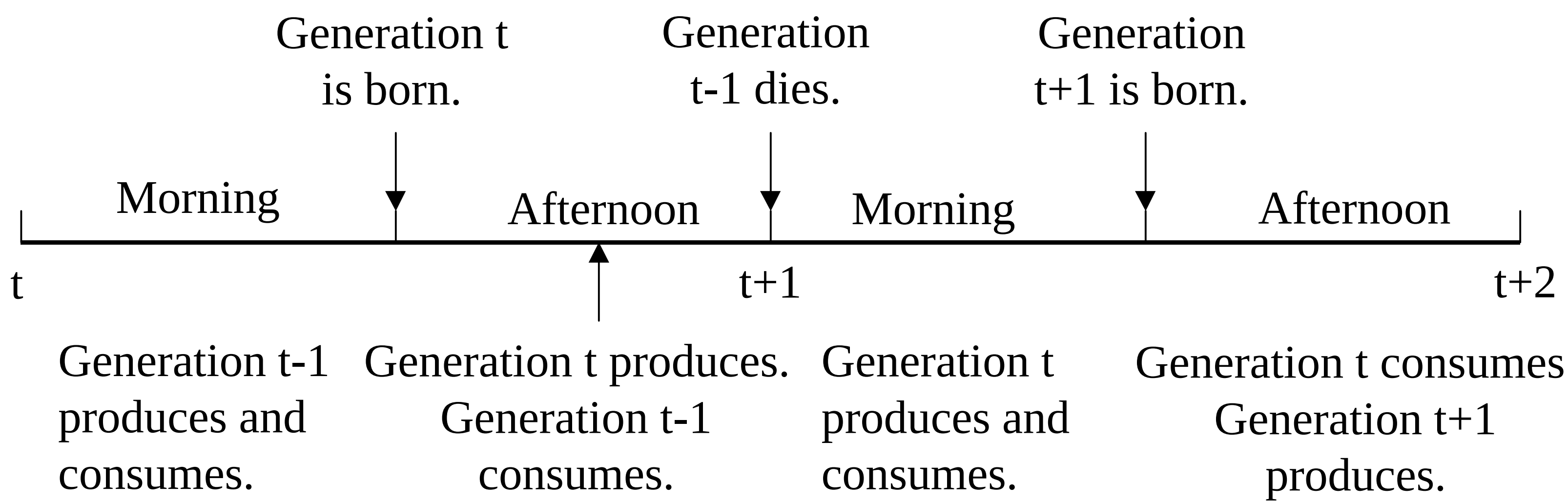
Kobayakawa, S., 1997, “The Comparative Analysis of Settlement Systems.” Centre for Economic Policy Research Discussion Paper No. 1667.

Kim, Y-S., 1997, “Liquidity, Interbank Market, and the Role of Central Bank.” Unpublished manuscript, Victoria University of Wellington.

Lacker, J.M., 1997, “Clearing, Settlement, and Monetary Policy.” *Journal of Monetary Economics* 40: 347-81.

Sargent, T.J. and N. Wallace, 1982, “The Real-Bills Doctrine versus the Quantity Theory: a Reconsideration.” *Journal of Political Economy* 90: 1212-36.

Figure 1: Model Timing



Notes

[1] For basic information Fedwire and CHIPS, see Bank for International Settlements (1993). Data on daily payment volumes are 1997 averages from Bank for International Settlements (1998).

[2] See, e.g., Bank for International Settlements (1997), Folkerts-Landau et al. (1997), or Emmons (1997).

[3] See e.g., Evanoff (1989).

[4] Their model shares many features with that of Sargent and Wallace (1982).

[5] In addition to the papers discussed below, see Freeman (1996a, 1999) and Kim (1997).

[6] We follow Sargent and Wallace (1982) and Champ et al. (1996) in restricting our attention to steady states. The steady-state equilibrium allocation of the Walrasian economy corresponds to the solution of the social planner's problem in the "golden rule" case where every generation's welfare receives equal weight in the planner's objective. More general characterizations of efficient allocations are given in the Appendix.

[7] In payments industry jargon, such an arrangement is known as a "BIS Model 1 Delivery-versus-Payment (DVP)" system; see Emmons (1997) for a discussion.

[8] Many central banks have historically made intraday credit available on a fully collateralized, zero-fee basis. See Bank for International Settlements (1997, Annex I). The European Central Bank currently offers Euro-denominated intraday credit for its RTGS system under similar terms. See European Central Bank (1998). By 2001, the Bank of Japan will also offer zero-fee, collateralized intraday credit over its RTGS system; see Bank of Japan (1997).

[9] Here, a key feature of bonds is not that they mature in the afternoon, but that their term to maturity (daily) is less than the frequency at which agents would like to trade (intraday).

[10] As Lacker (1997) points out, constraints imposed by RTGS would vanish if bonds could be sold short in arbitrary amounts.

[11] In practice, haircuts are imposed on virtually all forms of collateral.

[12] See, e.g., Folkerts-Landau et al. (1997, 40-41).

[13] In practice, central banks that pay interest on overnight balances pay slightly less than the interbank overnight rate. See, e.g., Borio (1997).

[14] The terms “sweeps” is used for computer programs that automatically move or “sweep” funds from reservable to non-reservable accounts.

[15] Fees are assessed for daylight overdrafts that exceed pre-set caps. See Emmons (1997, 28) for a summary of Federal Reserve policy on daylight overdrafts.

[16] For an empirical investigation of the sensitivity of payments volume to intraday interest rates on Fedwire, see Hancock and Wilcox (1996).

[17] Partial collateralization is an important component of the “Lamfalussy standards” for net settlement systems. See Bank for International Settlements (1990). Implications of the partial collateralization requirement are discussed in Emmons (1997) and Kahn and Roberds (1998).