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ABOUT THE LEVEL OF DAYLIGHT CREDIT, SPEED OF SETTLEMENT AND RESERVES IN ELECTRONIC PAYMENT SYSTEMS

by Paolo Angelini (*)

Abstract

Following the ongoing debate on risks in payment systems, gross settlement systems are increasingly considered as an alternative to netting. In these systems risk reduction is achieved through real time settlement of each transaction during the day via an exchange of monetary base, without a preliminary netting phase. The paper presents a simple dynamic model of a gross system, and shows that if banks are charged for the use of daylight credit by the central bank, an intraday market for funds is bound to arise. Within this context it is found that a network externality may cause banks to excessively reduce their reserve holdings and demand for interbank loans, relative to a social optimum. As a consequence, payments processing is relatively slow; this tends to worsen the quality of the information available to banks for cash management purposes, thereby reducing expected profits. In addition, risk levels are relatively high. The rise of the intraday market for funds, predicted by the model, does not by itself solve the problem. Some corrective policy measures are discussed.

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(*) Banca d'Italia, Servizio Studi.

1. Introduction[1]

Interbank payment systems have been the subject of extensive debate within the banking community over the last few years, in connection with the exceptional growth of the volume of transactions triggered by rapid financial innovation and technological progress. Interbank payments are customarily processed through netting systems, in which banks exchange "promises to pay" during the day and settle the balance at the end of the operating cycle, normally with base money. Since these intraday payments are provisional, i.e. they do not become good funds until settlement time, the banks that during the day send more payments than they receive can be viewed as holding a debit position vis-à-vis

1 This essay is a revised version of the third chapter of my Ph.D. dissertation at Brown University. I am indebted to Peter Garber for overall guidance and several helpful suggestions; Fabio Canova, David Weil, Roberto Serrano, Harl Ryder and Rajiv Vohra also made helpful suggestions. A special thanks to Oved Iosha for many, long and enlightening discussions and for his innumerable comments on previous drafts. I also express my gratitude to the Editorial committee of the Temi di Discussione for constructive criticism, and to C. Giannini, with whom I co-authored previous work related to the material developed in this paper. The usual disclaimer applies.

all the other banks in the system. These intraday debit balances, or daylight overdrafts, have been increasingly criticized on different grounds. One main reason for concern is that in several industrialized countries they have recently grown to large multiples of commercial banks' capital, making risk considerations of growing practical relevance. Liquidity as well as credit risk arise because one or more banks incurring daylight overdrafts may not be able to fund their positions by the time they come due. Further, these risks may become systemic in that the default of a bank with a large debit position may in turn cause its direct creditors to become insolvent, possibly triggering a domino effect of relevant proportions. Finally, since most clearing systems rely on the supply of end-of-day settlement services by a central bank, a moral hazard problem arises; if a bank suddenly defaults, its counterparts may expect central bank intervention to prevent large scale systemic disruption. Perception of these problems has raised serious concerns among central banks; wide-ranging risk reduction programs and substantial changes in interbank mechanisms are being implemented, with the main aim to protect the stability of financial markets, whose smooth functioning crucially depends on the reliability and efficiency of interbank payment networks. In particular, an arrangement alternative to netting is increasingly being considered: In the so-called gross settlement systems each transaction is settled individually and in real time during the day via an exchange of monetary base. Thus, provisional payments and intraday debit positions among banks are eliminated altogether, and risk is substantially reduced; on the other hand, the operation of these systems requires substantial amounts of reserves, entailing higher operational costs. A different kind of daylight overdraft may still arise in this context if the central bank allows participants to run negative balances on their accounts during the day, with the purpose to reduce liquidity requirements of the system.

Interbank payment arrangements are of theoretical relevance for at least two reasons. First, the size and allocation of financial risks (both between the central bank and commercial banks, and among the latter) depend on the configuration of the payment system, and it is not clear a priori what the optimal allocation is. In addition, the architecture of the payment system directly affects the functioning of the interbank market as well as the determination of money market interest rates, thereby impacting on the monetary policy transmission mechanism and on the costs and efficiency of the banking system.

Recently, much attention has been devoted to the first aspect. In the middle eighties the Federal Reserve, concerned about the size of daylight overdrafts on Fedwire, its own gross settlement system, as well as on the private netting system CHIPS, started a major risk reduction program that led to substantial changes in the operation mechanisms of both systems.[2] Towards the end of the decade the debate extended at the G-10 and the EEC level.[3] In Europe, central banks are among the main supporters of the gross settlement approach, due to its enhanced safety, whereas commercial banks worry that the high liquidity requirements of gross settlement systems could result in a substantial increase in operating costs (see European Banking Federation, 1993). In the wake of this still ongoing debate several EC and Eastern Europe countries are heading for the gross settlement option, although none of these projects of reform is based on a common model, partly due to the lack of theoretical results in this area. Needless to say, all these decisions involve huge investment over several years, both on the part of central banks and of the banking system.

These developments have spawned a large body of literature which, however, has mainly focused on policy oriented analysis or description of current arrangement and

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2 The most recent innovation was implemented in April 1994, when the Fed adopted a pricing mechanism for daylight overdrafts on Fedwire; in 1992 the latter had reached peak values of approximately US$ 170 billion per day. See Board of Governors of the Federal Reserve (1988), (1990), (1992), BIS (1993). Concern about risk in the US payment system was first raised by Humphrey (1986).

3 See BIS (1990b), Committee of Governors of the Central Banks of the EC Member States (1992a), (1993).

practices;[4] little formal analysis of such arrangements has been performed. Notable exceptions are Gelfand and Lindsey (1989), who present a welfare analysis of the various policies for the management of daylight credit, and VanHoose (1991), who builds a model of the federal funds market, focusing on the relationship between overdraft reduction mechanisms and the behavior of interbank interest rates, as well as on its monetary policy implications.

The present paper seeks to contribute to this strand of literature, in particular, to the analysis of gross settlement systems. The model presented is a simple dynamic generalization of the well-known static framework for the analysis of the demand for reserves under uncertainty;[5] it builds on the analysis in VanHoose (1991), shifting the focus on payment systems and modeling strategic interaction

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4 Payment system-related issues have been analyzed in a broad perspective and non formal context by Frankel and Marquardt (1983), (1987), Padoa-Schioppa (1988), (1989), (1992), Humphrey (1990a), (1990b), Garber and Weisbrod (1990), Passacantando (1991), Folkerts-Landau, Garber and Lane (1993), Angelini and Giannini (1993). On the issue of risk and risk reduction policies see the references in the previous two footnotes; see also Belton, Gelfand, Humphrey and Marquardt (1987), Mengle, Humphrey and Summers (1987), Evanoff (1988), VanHoose and Sellon (1989). Detailed descriptions of the interbank networks in the main industrialized countries are in BIS (1990a), (1993), Committee of Governors of the Central Banks of the EC Member States (1992b); see also Borio, Russo and Van den Bergh (1991).

5 See e.g. Orr and Mellon (1961), Grossman (1965), Miller and Orr (1966), Poole (1968), Baltensperger (1974).

between banks. The paper shows that if the central bank offers daylight credit at a cost, an intraday market for funds is bound to arise. In addition, the demand for reserves and for loans in the interbank market will be low, relative to a social optimum, due to an externality originating from the very structure of gross settlement systems: For the processing of payments in real time banks need liquidity, but since reserves entail an opportunity cost, each participant has an incentive to reduce its own holdings, expecting to be able to use some other participant's reserves. As a consequence, banks will tend to postpone the processing of payments; this will worsen the quality of the screen based information available to banks for cash management optimization, thereby reducing expected profits. In this context, it is shown that the creation of an intraday market for funds, predicted by the model, does not by itself eliminate the mentioned externality.[6] The paper discusses some alternative options for the pricing of

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6 Some of these effects have been pointed out in a non formal context by several authors. The possible impact of pricing of intraday liquidity on payment delays has been noted by Humphrey (1989). It has also been argued that pricing or restriction of daylight credit by the Federal Reserve is likely to generate an intraday market, either in the form of explicit loans for short intervals of time (e.g. hours or minutes) or through a premium on overnight loans delivered earlier on in the business day; see e.g. Simmons (1987), Evanoff (1988), Humphrey (1989), Stevens (1989). An external effect related to liquidity holdings was noted by Laidler (1977) within the context of money demand analysis.

daylight credit by the central bank which should restore optimality.

The analysis does not address the important issue of the choice between gross settlement and netting systems;[7] given the short time horizon considered for the optimization problem (the day), the framework proposed should however be suitable and the results obtained robust to extensions of the analysis endogenizing this choice.

The rest of the paper is structured as follows. The next Section contains a heuristic description of four main types of payment systems (netting systems and three types of gross settlement systems) which may be viewed as representative of the wide array of existing interbank arrangements; an effort has been made to illustrate the basic issues that lie at the core of the debate among alternative payment systems configurations, without attempting a rigorous treatment. In Section 3 some simple models of the gross payment systems described in Section 2 are sketched. In this Section I compare "free-market" outcomes, characterized as Cournot-Nash equilibria resulting from individual profit maximization by each bank, and cooperative outcomes, in which the choice variables are determined so as to maximize the <u>sum</u> of each participant's

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7 See Schoenmaker (1994).

profits. It turns out that in this context the cooperative outcome coincides with a social optimum, characterized by maximum profits and consumer surplus. Section 4 contains a discussion of alternative policy options that may be adopted to deal with the inconvenients analyzed in Section 3. Section 5 summarizes the main results.

2. Main models of electronic payment systems

The wide range of existing systems can be characterized in terms of four basic models.[8] In netting systems (also called clearing or net settlement systems) transactions are netted against each other during the business day. This can be done either bilaterally, or multilaterally through a central agent; in either case payments normally become irrevocable, or "final", only at the end of the day, when balances are settled.

In gross settlement systems payment messages are credited or debited to accounts that participating institutions hold with the central bank. The adjective "gross" refers to the fact that payments are settled individually, without a preliminary netting phase. I

8 A more detailed description of these system and a discussion of the issues dealt with in this Section can be found in Angelini and Giannini (1993), Angelini, Maresca and Russo (1993).

distinguish three main types in this class: Gross payment systems with and without daylight overdrafts and queuing systems.

In a gross payment system with daylight overdrafts the central bank allows participants to overdraw during the business day; thus, a sending bank may effect a real time transfer of funds even when its centralized account is empty. Payments become "final" in real time, since reserves are transferred to the receiving bank's account regardless of the actual availability of reserves on the sender's account;[9] on the other hand, if overdrafts are not fully collateralized the central bank may end up bearing some risk. On the contrary, on a gross payment system without daylight overdrafts a payment is rejected if the sending bank's centralized account does not have sufficient funds to cover it; thus these systems need substantially higher reserve levels to operate.

A queuing system can be viewed as an intermediate configuration between a clearing system and a gross system without daylight overdrafts. As in the latter, credit by the central bank cannot be resorted to; however, whereas in

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9 Loosely speaking, a payment message is said to be final when the receiving bank's account is credited with no possibility for the sending bank to claim the money back. Several alternative concepts of finality are spelled out by Mengle (1989). A payment is said to be provisional if it is not final.

gross system without daylight overdrafts payments messages lacking coverage are rejected, in queuing systems they are entered into a waiting queue and processed on a FIFO basis as soon as enough reserves flow in.[10]

Intuitively, these four options (net settlement plus the three varieties of gross settlement) may be thought of as alternative technologies to produce a given volume of payment messages, with reserves, bilateral (i.e. infra-bank) and central bank daylight overdrafts as inputs, yielding the isoquant in Figure 1. The technical rates of substitution between the various inputs are equal to one, since from the individual bank's viewpoint a payment worth X can only be processed with X of daylight credit from the central bank or commercial banks, or with an equal amount of reserves, or any convex combination thereof.

In practice, however, at the aggregate level nonlinearities might arise due to several factors.[11] A somewhat convex shape for Figure 1 at the system level is suggested by Table 1, which reports information relative to a few existing payment systems.

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10 See Mengle and Vital (1988), Vital (1989), (1990).

11 Among them is the impact of the specific system features on the velocity of circulation of reserves; e.g. caps on daylight overdrafts may induce banks to coordinate incoming and outgoing payments, thereby increasing the ratio of payments processed to overdrafts or to reserves.

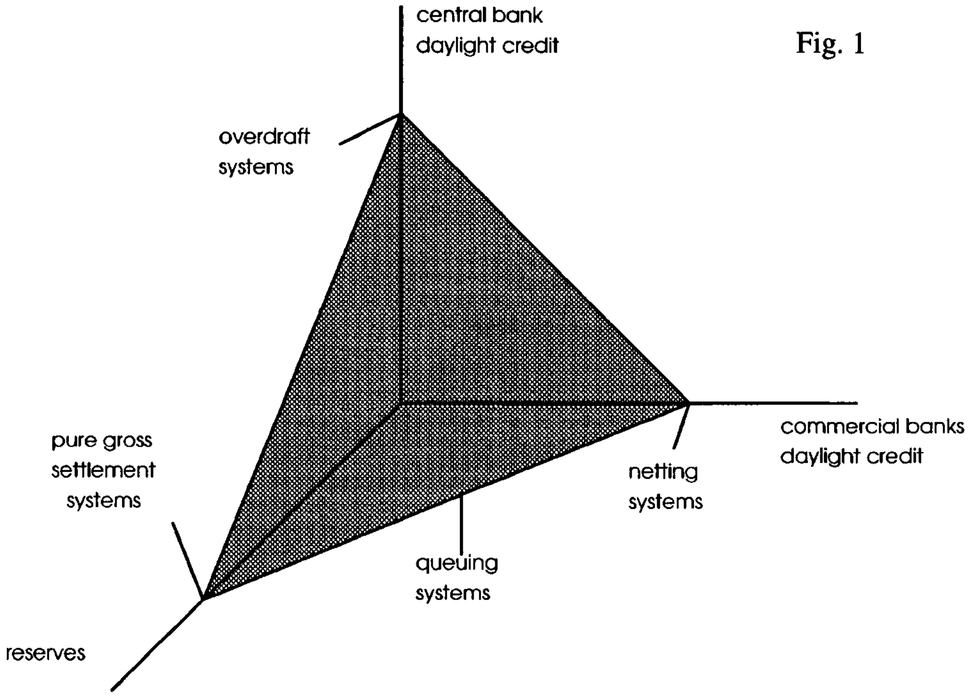

Fig. 1

Source: Angelini and Giannini (1993).

While the evidence reported in the Table is not conclusive, it suggests that the optimal configuration might be portrayed as an "interior solution" in Figure 1; in particular, queuing systems seem to fare better than either pure overdraft systems or pure netting systems.

As was noted above, the interest of policy makers and operators in the field has recently focused on gross settlement systems of various types, mainly due to their advantages in terms of risk management.

Tab. 1

OVERDRAFTS AND RESERVES IN SOME ELECTRONIC PAYMENT SYSTEMS
(as a ratio to payments volume; percentage terms)

	Central bank Overdrafts	Commercial banks Overdrafts	Reserves
Fedwire[1] (a)	11.2	0	5.4
(b)	9.8	0	6.2
SIC[2]	0	3.3	1.9
SIPS[3]	0	0	15.7
CHIPS[4]	0	7.1	0

Sources: Humphrey (1989), Vital (1990), Banca d'Italia, Annual Report for the year 1992, 1993.

NOTES
1. Fedwire is the US gross settlement system managed by the Federal Reserve, allowing participants to incur daylight overdrafts; rows (a) and (b) reports data for the second quarter of 1985 and 1988, respectively before and after ceilings on daylight overdrafts were imposed. For the three gross settlement systems the reserves figure accounts for end-of-day precautionary demand; this explains why the reserve level on Fedwire, a system with free daylight overdrafts, is not zero.
2. SIC is the Swiss queuing system, managed by the Swiss central bank; the data refer to April 1989. Since daylight overdrafts are formally eliminated in a queuing system, the column reports my own estimate of the value of overdrafts based on the average value of payments waiting in the queues.
3. SIPS is the Italian gross settlement system without daylight overdrafts, managed by the Banca d'Italia; the data refer to 1992.
4. CHIPS is the US netting system, managed by the New York Clearing House Association; the data refer to the second quarter of 1988, prior to the adoption of the loss sharing agreement currently being enforced.

In reality, the analysis of real world arrangements is complicated by the fact that virtually all existing configurations can be portrayed as interior points in Figure 1.[12]

There is no doubt, however, that the main comparative advantage of gross settlement systems lies in their globally lower risk level, due to the fact that quick payment finality can be achieved. Since rapid finality implies higher liquidity costs, for these systems to be desirable quick finality of payments must therefore be valuable. There are several reasons for this to be the case. At the social level, the main one has to do with the external nature of payment systems risk. Humphrey's (1986) simulation exercises showed that almost 40 per cent of the banks participating in the US netting system CHIPS could fail to settle following

12 Specifically, netting systems are increasingly adopting risk reduction measures of various type, such as limits to credit exposures and finality rules, which considerably blur the distinction between net and gross settlement systems. Finality rules are agreements among members of a clearing system aiming at ensuring the reliability of settlement (see e.g. Mengle, 1990; CHIPS, 1990). For instance, participants in the US clearing system CHIPS subscribe a loss sharing formula whereby losses accruing from the default of one or more participants are distributed among surviving members, so the risk of systemic settlement failure is substantially reduced. Thus, in principle a netting system with full collateralization should be represented in Figure 1 as a point on the reserves axis, similar to the "pure gross settlement" option. In the same vein, country-specific legal provisions may impair the degree of finality of payments handled by gross settlement systems. For instance, based on the so-called "zero-hour rule", embedded in the bankruptcy law of several industrialize countries, all transactions carried out during the calendar day in which a company's bankruptcy occurs are legally void (see e.g. Borio and Van den Bergh, 1993).

one participant's default. At the individual level, early final payments are useful for the receiving bank which avoids settlement risk, and for its client, who may access funds more rapidly. In addition, there may also be a demand for fast settlement services by sending clients; this is e.g. the case with Delivery Versus Payment arrangements.[13] Finally, in the international context quick finality may help reduce Herstatt risk.[14]

These considerations, which admittedly overlook a fair amount of complexity,[15] should convey an idea of the merits

13 With DVP the exchange of values (e.g. of bonds vs. cash) in fulfillment of a contractual obligation is synchronized so that neither party bears the credit risk related to delayed settlement or delivery. This arrangement is increasingly being used for foreign exchange contracts, securities, etc. and makes quick finality valuable.

14 This type of risk, named after the failure of the German Bankhaus Herstatt in 1973, arises in transactions among banks operating in different time zones. For instance, consider a Japanese bank buying French francs from an European bank. The Yen leg of the transaction will normally be settled by the Japanese bank in its national system, with a correspondent of the European bank. This operation will become final well before the French interbank payment system is closed, i.e. earlier than the franc leg of the transaction is irrevocably settled. Thus, the Japanese bank may incur a loss if the French bank fails to deliver the francs. This risk materialized recently with the BCCI failure.

15 For instance, in the international context unilateral adoption of gross settlement by one country may leave unaffected or even increase the credit risk borne by the banks of that country; in the example of the previous footnote, adoption of gross settlement by Japan would widen the time gap between settlement of the two legs of the foreign exchange transaction. Also, for the elimination of credit risk in financial transactions what is relevant is the simultaneity of the exchange (cash vs.

the gross settlement option. However, the existence of a market demand for quick final payments (or of the need to foster finality even in the absence of such demand) is a matter which deserves investigation for policy purposes, but is not strictly relevant in the context of this paper. In what follows I take for granted that there is such a demand and build on this assumption.

3. Simple models for gross payment systems analysis[16]

3.1 Basic notation and definitions

Assume that the market for electronic payment services is composed of n banks, interacting with a central agent offering settlement services. Banks may differ as to volume of payments processed, cost structures etc.; however, none of them is large enough to affect interbank rates. The business day, which begins at time t_0 (e.g. 8:00 a.m.) and ends at time t_1 (e.g. 6:00 p.m.), is subdivided into m

securities, currency vs. currency, etc.; see Angelini and Giannini, 1993), whereas rapid finality is important for the elimination of market risk. For a thorough analysis of payment system-related issues, see Board of Governors of the Federal Reserve (1988).

16 The analysis presented in this Section abstracts from a number of details which I did not deem essential for my purpose, but need not be of secondary importance; for a thorough description of an interbank market and of a gross settlement system, see Stigum (1990).

intervals of length $(t_1 - t_0)/m$ (e.g. 10 minutes). Banks face a demand for payment services by their clients, who come in during the day to send money to their business counterparts, holding accounts at other banks. Let $\mu_t^i \in [0,\infty)$ be the monetary value of clients' demands collected by bank i over interval ending at time t. For reasons that will be made clear in what follows, the bank may decide to withhold some payments requested by clients, waiting to send them at some later period; this may create a backlog of payments that clients requested to be sent in period t but the bank chooses to send only in period $t+j$. Let z_t^i be the amount of payments waiting to be sent at time t; this amount is composed of the sum of new payment orders μ_t^i and the backlog from previous periods, which I denote by $a_{t-1}^i \in [0, z_{t-1}^i]$:

(1) $$z_t^i = \mu_t^i + a_{t-1}^i, \qquad a_{t_0}^i = a_{t_0-1}^i = \mu_{t_0}^i = 0 .$$

Banks also send and receive payments on their own account. Specifically, banks that expect to end the day with excess funds will turn to the interbank market to invest them, and to do so they will send payments; similarly, banks that find themselves short will borrow and will therefore receive payments. Let v_t^i be the amount borrowed ($v_t^i>0$) or lent at time t and flowing through the settlement account. Lending and borrowing takes place at the same interbank rate $r_{b,t}$, which can be thought of as the overnight rate, or any other short-term money market rate. The total volume of funds flowing out of bank *i*'s account at time *t* is then:

$$(2) \qquad (z_t^i - a_t^i) + \max(0, -v_t^i).$$

where $a_t^i > 0$ indicates that some outgoing payments are being withheld. Similarly, I define the total amount of funds received by bank *i* in the same period as:

$$(3) \qquad y_t^i + \max(0, v_t^i).$$

where:

$$(4) \qquad y_t^i = \sum_{j \neq i} b_t^{ji} (z_t^j - a_t^j).$$

and the b_t^{ji} are nonnegative weights, $\sum_{i \neq j} b_t^{ji} \equiv 1$. Specifically, b_t^{ji} is the share of bank *j*'s total outflow of payments at time *t* going to bank *i*. In both (2) and (3) the first term summarizes the payment activity performed on behalf of clients, while v_t^i denotes activity in the interbank market.

A last category of payments originates from central bank activity. For the present purposes I consider operations affecting *daylight* liquidity, hence I define $Q_t > 0$ to be repurchase agreements offered by the central bank at time *t* at rate r_Q; I assume that an injection of reserves is distributed evenly across banks, so that $q_t^i = Q_t / n = q_t$ for every i, t. All operations mature at the end of the business day, hence $q_{t_1} \equiv -\sum_{s=t_0}^{t_1-1} q_s$.

Banks are not allowed to withhold payments indefinitely, as they would clearly do it if they could. Thus, I assume that all the payments requested by customers must be sent by the end of the business day, so that the following constraint must hold:

(5) $$\sum_{s=t_0}^{t_1}(z_s^i - a_s^i) = \sum_{s=t_0}^{t_1}\mu_s^i .$$

Denote by $R_{t_0}^i$ the beginning-of-day level of reserves, i.e. the initial liquidity that the bank holds "idle" on its account for the purpose of making payments, which will in general be equal to the previous end-of-day position. Thus, the liquidity position of the bank's settlement account at any time t will be given by the algebraic sum of outgoing minus incoming payments, both on clients' and own account, plus central bank repurchase agreements q_t, plus the beginning-of-day level of reserves $R_{t_0}^i$; using (3) and (2) and summing over t, I get an expression for the monetary value of this liquidity position:

(6) $$D_t^i \equiv \sum_{s=t_0}^{t}\left[z_s^i - a_s^i - y_s^i - v_s^i - q_s\right] - R_{t_0}^i .$$

D_t<0 means that the bank has excess liquidity on its settlement account, whereas D_t>0 implies that the bank is incurring an overdraft. In the latter case the bank may face costs due to reserve deficiency. I define $r_{d,t}$ to be the rate charged by the central agent for the use of overdrafts in period t. For $t=t_1$ $r_{d,t}$ is the discount rate, whereas for $t<t_1$ it is the rate charged for the use of daylight overdrafts, which may be positive or zero, depending on the specific type of payment system considered.

Concerning revenue from payment processing, I assume that banks charge a fee proportional to the amount transferred, which is imposed only on outgoing payments.[17] I describe bank i's revenue by a function g^i and assume that delaying the settlement of payment messages ordered by clients (setting $a_t^i>0$ for some t) entails a monetary loss. This may e.g. be the case if customers demand a compensation when payments are delayed. Alternatively, one may think that the day's revenue is fixed and that g^i represents expected future revenue from payment services; in this case, clients' dissatisfaction caused by delayed sends will generate a

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17 In reality the banking system also supplies (and collects revenue from) payment receiving services. For simplicity I do not consider this category. Moreover, fees are generally fixed, i.e. not related to the amount being transferred. Here I assume that banks are not indifferent to payments size, which affects the overall liquidity and credit risk-related costs they face and impose on each other.

revenue loss through reduction of future demand. In both cases, a direct relationship between revenue and speed of settlement stems from the intrinsic usefulness of gross settlement, which was discussed at some length in Section 2 and is taken for granted in this stage of the analysis. Thus, let the period t money value of the revenue from payments activity be $g_t^i = g^i(a_t^i, z_t^i)$ and assume $g_1 \leq 0$, $g_1(0, z_t^i)=0$, $g_{11}<0$. Concavity captures the idea that small delays will have little impact on revenue, but as they become large customers' dissatisfaction will grow substantially, and heavier consequences on revenue will accrue.[18] The main results of this Section would follow, under reasonable conditions, even if g^i were linear in a_t^i, as would e.g. be the case if banks' clients minimized a quadratic cost function. Thus, none of the above assumptions is strictly relevant for the derivation of the following results, with the exception of $g_1(0, z_t^i)=0$. The consequences of relaxing this assumption, which plays the role of an Inada condition, will be discussed in Section 3.3.

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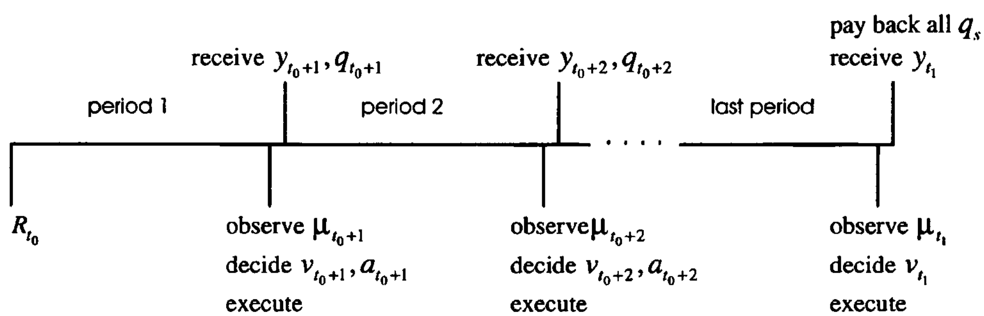
18 A simple version of g^i could be $g^i(a_t^i, z_t^i)=pz_t^i[1-(a_t^i/z_t^i)^2]$, where p is the fee for payment sending services. The demand for sending services faced by the bank will clearly depend on p, which could be treated as a choice variable. However, since normally fees are updated at most only few times during the year, I assume that p has been determined in a previous stage. This assumption allows me to focus on the time horizon that is the object of the analysis, i.e. the day, without additional complications that would not affect nor add further insight to the results derived in what follows.

3.2 Timing of the operations and information structure

As already mentioned, during the business day banks receive payments requests by clients, who come in until closing time t_1. Payment orders are collected over m intervals and sent simultaneously in a lump at the end of each interval. Omitting superscripts, the timing of the system operation for bank i is the following:

Fig. 2



where e.g. period 1 extends between t_0 and t_0+1. Reception of incoming funds y_s and q_s and decision making regarding v_s (the amount to be borrowed/lent in the interbank market) and a_s (the amount of payments to withhold) is simultaneous; the Figure displays a lag between the two instants to emphasize that when the decision is made uncertainty remains over incoming payments. I assume that from the banks' viewpoint the μ_t^i (i=1,2,..n, s=t_0,...t_1) are exogenously given nonnegative stochastic variables, jointly distributed according to a known unconditional density.[19]

This timing generates three sources of uncertainty. First, the level of the demand is unknown to banks until clients come in. At the end of interval t μ_t^i is observed by bank i, but uncertainty remains over μ_s^i for $s>t$. A second source of uncertainty is that at time t, when a decision concerning the payments to send must be made, banks do not observe incoming payments which other banks send on behalf of their clients, but only the past history of payments received up to time t-1; thus, y_{t-1}^i is observed but uncertainty remains over y_s^i for $s\geq t$. Finally, banks face uncertainty concerning market interest rates. At time t the interbank rate $r_{b,t}$ will be determined through a market clearing condition, whereas for $s\geq 1$ banks will view $r_{b,t+s}$ as a random variable.

I denote by $f(\cdot|I_t^i)$ the joint density function of the random variables $\{r_{b,s},\mu_s^i\text{: } i=1,2,..n,\ s=t_0,...t_1\}$ conditional on information available to bank i at time t, and by $E(\cdot|I_t^i)$ its conditional expectation. The unconditional distribution $f(\cdot)$ and the functions g^i are assumed to be common knowledge; the

19 The assumption of exogeneity of the demand for payment services is warranted by the short time horizon of the analysis: it would be unrealistic to think that customers could react *within the day* to banks decisions having an impact on demand, such as fee variations or excessive delays. The latter are allowed to impact on demand over a longer time horizon via reduction of (future) bank revenue.

weights b_t^{ji} are known to bank i for every j, t. Note for further reference that $E(-D_{t_1}^i | I_t^i)$ represents bank i's targeted end-of-day level of reserves, i.e. the new desired level of $R_{t_0}^i$:

$$R_{t_0}^{i*} \equiv E(-D_{t_1}^i | I_t^i). \tag{7}$$

Finally, the following assumptions are made: there are no reserve requirements; the interest rate earned on free reserves is zero; there are neither transactions nor adjustment costs related to borrowing or lending operations;[20] banks are risk neutral. All assumptions but the last one are made merely to save on notation. The assumption of risk neutrality is standard in this literature as it greatly simplifies the analytical treatment; it should be relatively harmless in this context, given that the focus of the analysis is not on interest rate behavior.

The notation introduced thus far is summarized in the following Table:

[20] In the model of Section 3.3 a positive demand for end-of-day reserves stems from the fact that banks face uncertainty in the last period. VanHoose (1991) achieves the same purpose by assuming quadratic adjustment costs for interbank market transactions and no uncertainty in the second period. The analysis of Section 3.3 should carry on to the alternative framework.

Tab. 2

Deterministic variables	r_Q	: interest rate on daylight repurchase agreements;
	$r_{d,t}$	: interest rate on overdrafts at the end of period t;
	q_t	: daylight repurchase agreements.
Stochastic variables	$r_{b,t}$	: interbank rate;
	y_t^i	: payments received by bank i at the end of period t;
	z_t^i	: payments to be sent by bank i at the end of period t;
	μ_t^i	: payments demanded by clients in period t.
Control variables	a_t^i	: share of z_t^i that bank i decides to withhold;
	v_t^i	: funds borrowed (v_t^i>0) or lent in the market.

3.3 Gross payment systems with costly daylight credit

In this Section I consider the problem faced by a bank operating in a gross payment system in which daylight credit from the central bank is available at a charge; this problem can be cast within a dynamic stochastic optimization framework and analyzed by appropriately modifying the setup devised by the literature on precautionary demand for reserves. For the sake of simplicity, in what follows I consider the case of two banks, A and B, operating for two periods (morning and afternoon); this makes the discussion of the first order conditions easier without affecting the generality of the conclusions reached.[21]

[21] In particular, at the cost of a heavier notation the problem can be rewritten for the general m periods, n banks

Thus, setting t_0=0 for ease of notation, equation (1) yields $z_1^i=\mu_1^i$, $z_2^i=\mu_2^i+a_1^i$; therefore, the relevant stochastic variables are $\{\mu_1^B, \mu_2^B, \mu_1^A, \mu_2^A, r_{b,1}, r_{b,2}\}$. At the end of period 1 bank A observes the demand for outgoing payments by its own clients and the interbank rate, hence $I_1^A=\{\mu_1^A, r_{b,1}\}$; uncertainty remains on μ_1^B, μ_2^B, μ_2^A and on $r_{b,2}$. Thus, let $\bar{\mu}^A$ be the (unobserved) net inflow of funds due to operations performed on behalf of clients, $\bar{\mu}^A \equiv (\mu_1^B+\mu_2^B-\mu_2^A)$, and denote by $\bar{F}$ its c.d.f. and by F that of the marginal distribution of μ_1^B; suppressing superscripts relative to bank A, the problem for the latter at the end of the first period can be written as follows:[22]

$$
(8) \qquad \underset{[v_1, v_2, a_1]}{Max} \quad g(a_1,\mu_1) - r_{d,1}\int_0^{k_1} D_1 dF(\mu_1^B | I_1) - r_{d,2}\int_{-\infty}^{k_2} D_2 d\bar{F}(\bar{\mu}|I_1) - \sum_{s=1}^{2} v_s E(r_{b,s}|I_1) - r_Q q_1
$$

where:

$$
(9) \qquad \begin{aligned} k_1 &\equiv \mu_1 - a_1 + a_1^B - v_1 - R_{t_0} - q_1 \\ k_2 &\equiv \mu_1 - v_1 - v_2 - R_{t_0}. \end{aligned}
$$

---

case without affecting the structure of the first order conditions (10)-(12) derived below, although extension to the *m* periods case may raise issues of multiplicity of equilibria.

22 Problem (8) can be rewritten conditional on information available in any other period; this just affects the notation but not the structure of the first order conditions derived below.

and the $E(\cdot)$ operator denotes expectation with respect to the marginal distribution of $r_{b,2}$.[23] The first term of (8) is the revenue function described above; the second term gives the expected cost of daylight overdrafts in period 1. The third term captures the expected cost of resorting to the discount window at the end of the day; it is the equivalent of the term appearing in the well-known static model for the analysis of the demand for reserves under uncertainty.[24] The k_i are defined so as to integrate over the subspace where realizations of the random variables μ_1^B, μ_2^B and μ_2^A yield positive overdrafts (D_t>0); over this region, as already mentioned, banks will pay the cost of resorting to daylight overdrafts in the first period (term multiplied by $r_{d,1}$) and to the discount window in the second (term multiplied by

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23 Gross revenue for the second period, $g(a_2,z_2)$ is not included in (8) since due to constraint (5) all payments must be sent by the end of the day, implying that a_2^A must be equal to zero. For the same reason D_2 is not a function of a_1^A; formally, constraint (5) is incorporated in (8) through direct substitution into D_2. Substituting (1) and (4) into (6), and noting that in the two banks, two periods case b_t^{ji}=1 for every i, j, t, I get the following expressions for D_1 and D_2 :

$$D_1 = \mu_1 - a_1 - \mu_1^B + a_1^B - v_1 - q_1 - R_{t_0}$$
$$D_2 = \mu_1 + \overline{\mu} - v_1 - v_2 - R_{t_0}.$$

where superscripts relative to bank A have been omitted. Substituting these equations in problem (8) the derivation of the first order conditions (10)-(12) is straightforward.

24 See e.g. equation (3) in Baltensperger (1974).

$r_{d,2}$).[25] The cost of borrowing (or, depending on the sign of v_t, the gain from lending) in the interbank market is given by the terms in the summation operator.

The formulation of problem (8) is relatively standard; the main novelties are represented by g^i, expressing revenue as a decreasing function of settlement delay, and by the second term, which gives the expected cost of daylight overdrafts. These two terms capture the trade-off faced by the sending bank: delaying payments will generate loss of revenue due to customer dissatisfaction, but will reduce the expected cost of daylight overdrafts.

Omitting again bank A's superscripts, the first order conditions with respect to v_1^A, v_2^A and a_1^A yield, in the order:

(10)
$$r_{d,1}\int_0^{k_1} dF(\mu_1^B | I_1) + r_{d,2}\int_{-\infty}^{k_2} d\overline{F}(\overline{\mu} | I_1) = r_{b,1}$$

(11)
$$r_{d,2}\int_{-\infty}^{k_2} d\overline{F}(\overline{\mu} | I_1) = E(r_{b,2} | I_1)$$

(12)
$$r_{d,1}\int_0^{k_1} dF(\mu_1^B | I_1) = -g_1 .$$

25 $r_{d,t}$ will be fixed and small for $t<t_1$ and substantially higher for $t=t_1$. For instance, the fixed rate on daylight overdrafts recently introduced by the Federal Reserve on Fedwire, the US interbank gross settlement system, is 24 basis points (see BIS, 1993).

Solving the eight equation system formed by (10)-(12) for A and B plus the two market clearing conditions $\sum_{i=A,B} v_t^i = 0$ for t=1, 2 yields a simultaneous Cournot-Nash equilibrium.[26] This will determine market clearing interbank rates $r_{b,t}$ as well as optimal values for v_t^i and a_t^i as a function of policy rates $r_{d,t}$, initial level of reserves and payment services demanded; I call these v_t^{im} and a_t^{im} for i=A, B. Note that although a closed form expression cannot be computed, solution of the system will yield reaction functions for banks A and B, as e.g. B's choice variable a_1^B appears in the limit of integration k_1 given in (9).

I now assume $\sum_{i=A,B}(\mu_1^i - R_{t_0}^i)>0$. That is, in the aggregate the amount of funds processed by the interbank system in period 1 is larger than the reserve level; for most existing gross settlement systems this assumption is quite reasonable, as the former is a large multiple of the latter, as was shown in Table 1. I can now state the following proposition:[27]

26 The problem solved by each bank can be seen as a static game of imperfect information, characterized by the existence of a Bayesian equilibrium. In particular, assuming that μ_1^B and $\bar{\mu}^A$ have uniform distributions, as in VanHoose (1991), that banks A and B are identical, and using the specification of g^i given in footnote 18, the derivation of explicit solutions for the choice variables is straightforward, and an unique equilibrium can easily be computed.

27 The proofs of propositions 1 through 5 are given in the Appendix 1.

Proposition 1: In equilibrium: *i)* $r_{b,1} > E(r_{b,2}|I_1^i)$;
ii) $a_1^{im} > 0$ for i=A, B.

Proposition 1 says that when the sending bank is charged for daylight overdrafts an intraday market for reserves will materialize, either in the form of explicit contracts allowing participants to use funds for a limited time (e.g. hours or minutes), or more likely, given the cost implicit in writing formal contracts, in the form of a premium on overnight loans delivered earlier during the business day. At the same time, input of payments will be delayed ($a_1^{im} > 0$) to avoid the cost of overdrafts, so a backlog will tend to accumulate.[28]

These results are fairly intuitive. In a gross settlement system reserves have a role to play during the day (and not just at the end of it, like in netting systems) in that they allow banks to avoid the loss of revenue related to payments delay. As long as $r_{b,1} = E(r_{b,2}|I_1^i)$ banks will expect to use reserves at no cost, since they may borrow in

28 In addition to delaying the input of payments, pricing daylight overdrafts may in practice trigger several other responses from banks, not analyzed in the model of this Section. For instance, banks may try to coordinate incoming and outgoing flows; see Humphrey (1989) for a thorough analysis of these reactions. Clearly, if some of these alternative options are relatively inexpensive, the impact of pricing on payments delays will be comparatively weaker.

the morning and lend back at the same (expected) rate in the afternoon; this will create an excess demand for reserves in the morning, which will drive a wedge between interbank rates in the two periods.

I now derive the necessary conditions for a minimum for the cooperative problem, resulting from the determination of bank A's choice variables to minimize the sum of the costs of banks A and B. Specifically, noting that in the two bank, two period case equation (4) yields $y_1^B = \mu_1^A - a_1^A$ it can be checked that (10) and (11) hold unchanged, whereas the equivalent of (12) becomes:

$$(13) \qquad r_{b,1}\Big[\int_0^{k_1^A} dF(\mu_1^B | I_1^A) - \int_0^{k_1^B} dF(\mu_1^A | I_1^B)\Big] = -g_1^A.$$

Let the solution of the system of first order and market clearing conditions for the cooperative problem be v_t^{ic} and a_t^{ic} for i=A, B. I can now state the following results.

<u>*Proposition 2*</u>: $a_1^{ic}=0<a_1^{im}$ for i=A, B.

Proposition 2 says that the trajectory for a_t^i in the cooperative outcome always lies above the optimal trajectory for the free-market equilibrium; the sending bank has an incentive to deviate from a situation of cooperative optimum by decreasing its demand for loans in the interbank market and the percentage of payments settled before the end of the business day.

Two points are worth mentioning. First, note that within this framework the cooperative outcome coincides with a social optimum. Indeed, joint profits are maximized by definition; interpreting the functions g^i as the product of a fee for payment processing services times a demand schedule decreasing in the delay a_t^i (see footnote 18), at $a_t^i=0$ consumer surplus is maximized as well. Secondly, the creation of an intraday market for funds does not eliminate the externality related to reserve holdings. This depends on the fact that in the Nash equilibrium banks equate at the margin the revenue loss from customer dissatisfaction and the reduction in the expected cost of daylight overdrafts, i.e. the right and left hand sides of (12), respectively. Conversely, in the cooperative outcome delaying yields zero benefits because it reduces bank A's expected overdraft cost, but increases by the same amount that of bank B.

Letting m and c superscripts denote expressions evaluated at the free-market and cooperative outcomes, respectively, the following results hold.

Proposition 3: *i)* $v_t^{ic} > v_t^{im}$ for t=1, 2;
ii) $R_{t_0}^{ic*} > R_{t_0}^{im*}$;
iii) $D_t^{im} > D_t^{ic}$ for t=1, 2.

Proposition 3, which is a direct consequence of proposition 2, maintains that in a free-market equilibrium the demand for interbank loans is lower than it would be in a cooperative optimum. As a consequence, for given interest rates a lower beginning-of-day desired reserve level and a higher use of daylight credit will materialize.[29] This implies that even in systems charging senders a proportional fee for daylight overdrafts risk-related costs are higher than they would be in a no-externalities world.

For the case $n \geq 3$, the following result holds.

Proposition 4: Due to the information structure, the sum of banks' expected profits in the second period is lower in the free-market equilibrium than in the cooperative case.

Since the solution to the cooperative problem yields the monopolistic outcome, joint profits are trivially going

29 The same conclusion could be reached from problem (8) by considering $R_{t_0}^i$ as a choice variable with opportunity cost equal to the interbank rate of the previous day, and noting that proposition 3 applies to $R_{t_0}^i$ as well as to v_t^i. Note the close resemblance with the standard analysis of public goods: the demand for reserves falls short of the optimum for the same reason as the demand for a public good does.

to be higher in this case than when banks compete. However, proposition 4 points out a different source of inefficiency of the competitive equilibrium, which originates from the fact that the practice of delaying payments will reduce the quality of the information available to the receiving bank: If a_1^B is unknown to bank A, the latter may have problems distinguishing a situation in which the inflow of payments is low because the realization of μ_1^B is low from one in which μ_1^B is large but bank B chooses to withhold a relevant portion of it. This represents a potentially negative aspect of the practice of delayed sends, which so far have been mainly viewed as an efficient way of reducing the level of daylight overdrafts at the system level (see Humphrey, 1989, 1990).

The free-market sub-optimality result of proposition 2 stems from the fact that daylight liquidity is costly. In order to quickly process payments banks must either overdraw at rate $r_{d,1}$, borrow from the central bank at rate r_Q, or borrow in the interbank market at a cost equal to the differential between the interbank rate in the morning and in the afternoon. Banks' behavior will depend on the level of these policy rates, but also on the revenue loss caused by payment delays: If even minor delays trigger heavy retaliation by clients, banks will clearly be reluctant to put off payments to the afternoon. In this context it is important to relax the assumption $g_1(0, z_t^i)=0$ made in Section

3.1. This assumption means that when delays are very small an increase in the delay will have a negligible impact on revenue. Assume instead that $|g_1^i(0,\cdot)|>0$.

Proposition 5: *i)* If $|g_1^i(0,\cdot)|>r_{d,1}\int_0^{k_1} dF(\mu_1^B|I_1)$ then $a_1^{im}=0$;
ii) If $|g_1^i(0,\cdot)|>r_Q$ then $a_1^{im}=0$.

Proposition 5 says that if delaying payments entails a heavy loss of revenue, banks will choose not to delay, and the free-market outcome will be efficient; proposition 1.*i*) will still hold true, whereas proposition 1.*ii*) as well as propositions 2, 3 and 4 will not. This is hardly surprising: If the marginal cost of delaying payments were uniformly very high, banks would always prefer to borrow immediately rather than delay. Proposition 5 highlights that although the policy rates $r_{d,1}$ and r_Q can be set independently from each other by the central bank, only one is going to have an impact on the behavior of commercial banks: If r_Q (or alternatively, $r_{d,1}$) is set very low, the inequality in 5.*i)* (in 5.*ii)*) will hold regardless of the level of $r_{d,1}$ (r_Q) and optimality will be restored.

3.4 Other main types of gross settlement systems

Consider a gross payment system in which the central bank supplies free daylight overdrafts. This implies $r_{d,1}$=0 in problem (8), which collapses to the standard static model of the demand for reserves under uncertainty; it is straightforward to check that bank i will choose to set v_1^i=0 and a_1^i=0, thereby maximizing daylight overdrafts. This is not surprising: No effort will be made to economize on the use of daylight credit since the supply cost is borne by the central agent. The same solution will hold also for the cooperative outcome.

Consider next a gross settlement system in which daylight overdrafts are allowed free of charge, but a ceiling k is imposed on them. In other words, the constraint

$$D_t^i \leq k, \qquad k \geq 0 \tag{14}$$

is imposed for $t<t_1$. Then, letting λ be the Lagrange multiplier associated with constraint (14), problem (8) above becomes:

$$\max_{[v_1, v_2, a_1]} \quad g(a_1, \mu_1) - r_{d,2}\int_{-\infty}^{k_2} D_2 d\overline{F}(\overline{\mu}|I_1) - \sum_{s=1}^{2} v_s E(r_{b,s}|I_1) - r_Q q_1 + \lambda(k - D_1) \tag{15}$$

where bank A's superscripts have again been omitted. It is straightforward to check that when the constraint is binding a system of first order conditions identical to (10)-(12) is obtained in which the term $r_{d,1}\int_0^{k_1} dF(\mu_1^B | I_1)$ is replaced by λ. With the appropriate changes, propositions 1 through 5 can be checked to hold unchanged.

In general, if k is set very low in the presence of low aggregate reserve levels, the system may come to a standstill: every bank expects to receive payments in order to be able to send out its own. For these systems to function, injections of daylight liquidity through repurchase agreements of the type described in Section 3.1 will be required.

The analysis of this Section applies also to queuing systems, in which k=0. In these systems the externality related to reserve holdings is still present, and generates problems of delayed finality analogous, at least qualitatively, to those detected for the other systems.[30]

30 In this respect the velocity of circulation of reserves, which has been implicitly assumed to be constant in the above analysis, plays a crucial role. Empirically, queuing systems seem to fare better than others. In the Swiss system SIC, the only queuing system operating at present (see Table 1), velocity has consistently been higher than in every other existing system (see Humphrey, 1989). This is partly due to the fact that the procedure triggering payment sends is completely automatic.

However, since banks have no reason to delay the input of outgoing payments, which are automatically placed in a waiting queue, and since information concerning the size of incoming queues can be made available in real time to the receiving bank,[31] the informational problems synthesized in proposition 4 do not arise.

4. Assessment and policy implications of the results

Proposition 5 highlights that the level of the policy rates r_Q and $r_{d,1}$, relative to the marginal revenue loss from delaying payments, $|g_1^i|$, are crucial in this context. If the system is to work properly under pricing of daylight credit, the sending bank's marginal revenue loss from delaying payments must rise sufficiently rapidly as a_t^i is increased. One reason why this may fail to happen is that delaying payments generates external costs that are borne by the receiving bank: the information available to the latter worsens; other things equal, its demand for reserves must be increased; credit and liquidity risks are increased. Thus, the marginal cost of payment delays *perceived* by the sending bank may be very low.[32]

31 This is the case in the Swiss system SIC.

32 The available empirical evidence on the issue suggests that banks are not very concerned with intraday delays. For instance, on SIC the average value of the queues, i.e. of delayed payments, often exceeds 40 per cent of the total daily volume. More evidence will become

A first policy prescription stemming from these considerations is that for the proper functioning of a gross settlement system the central bank, while safeguarding itself against moral hazard and credit risk, should supply intraday liquidity so cheap as to allow either inequality of proposition 5 to hold.[33] For economies characterized by payment flows that are small relative to commercial banks' portfolio of eligible bonds and/or reserve requirements, this can be done in several ways: (a) zero interest rate daylight repurchase agreements may be used to inject liquidity at the beginning of the day and drain it at the end, when it is no longer needed; (b) banks can be allowed to mobilize required reserves during the day at zero cost. In both cases, the cost of daylight liquidity can be reasonably assumed to be zero for all practical purposes; settlement-related risks would be borne by commercial banks, and systemic risk would be entirely eliminated.

These solutions, however, will not work in highly financially developed systems, characterized by large transaction volumes and correspondingly high liquidity

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available as data on Fedwire after the enforcement of the new pricing policy (see footnote 2) are released.

33 This policy would likely hamper the creation of a private market for intraday funds, which is the main reason why some authors (e.g. Evanoff, 1988) claim that the central bank should charge a relatively high price for daylight credit.

requirements. For these economies it seems unrealistic to assume zero cost daylight liquidity. Even if the central bank offered repurchase agreements at zero interest, r_Q could be interpreted as the cost of immobilizing the bonds used in the operations, since the fact that such bonds cannot be used for trading during the day will hamper portfolio management.

Thus, for economies with highly developed financial markets a second policy prescription, complementary to the previous one, stems from the following considerations. The analysis of Section 3 is based on the idea that daylight credit benefits the sending bank, which should therefore be properly charged for its use. However, benefits spill over the receiving bank as well, as was seen above, in terms of better information, lower demand for reserves and risk levels. In short, the receiving bank may be willing to share the cost of daylight overdrafts incurred by the sending bank, if a proper mechanism is devised. While the previous analysis has made clear that the rise of an intraday market for funds does not solve the problem, banks might well reach a spontaneous agreement on this mechanism;[34] however, such market-based solution to the problem is hindered by the fact

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34 For instance, receiving banks could agree to give sending banks a discount on payments settled early during the business day, thereby reducing incentives to withhold payments for the latter.

that a pricing agreement would require negotiation at the system level and widespread agreement among banks.

Suppose that the central bank supplies daylight credit under a zero expected profits policy,[35] but that in order to provide adequate compensation for risk $r_{d,1}$ must be large enough to generate positive delays, worsening of the information structure etc., i.e. a sub-optimal situation in the sense defined in propositions 1 through 4 of Section 3. A pricing mechanism capable of restoring optimality would then be the following: Charge the sending bank $r^s_{d,1} \equiv \alpha r_{d,1}$ and the receiving bank $r^r_{d,1} \equiv (1-\alpha) r_{d,1}$, choosing $\alpha \in [0,1]$ so that the strict inequalities of proposition 5.*i)* or 5.*ii)* hold, once $r_{d,1}$ is replaced with $r^s_{d,1}$. This configuration, while leaving the door completely open to a market-based solution, would eliminate reserves externalities as well as systemic risk-related ones; it would also eliminate incentives against rapid finality of payments, so that the information problems highlighted in proposition 4 would not arise. As long as $\alpha>0$ the sending bank, that has effective control over daylight credit, would still have an incentive to cut down on its use. The revenue from the charges would be the premium going to the central bank for the insurance provided against

35 In principle, this can be done by setting the interest rate on uncollateralized daylight credit, $r_{d,1}$, so as to equate the discounted flow of revenue from the supply of daylight credit and the discounted expected losses from settlement defaults.

settlement and systemic risk. The prescription of a low-cost supply of daylight liquidity would apply in this case as well, to prevent banks from colluding or seeking cheaper and riskier alternatives to gross settlement.[36]

Finally, let us look at the monetary policy implications of the above results. It is worth stressing that the above prescription of keeping the cost of liquidity low applies to the price of intraday liquidity, i.e. to the policy rates r_Q and $r_{d,1}$, and not to that of end-of-day liquidity, i.e. the discount rate $r_{d,2}$; intraday liquidity can indeed be controlled through these new, specific policy rates quite independently of the traditional monetary policy tools. As can be checked from equations (10)-(12), changes in the policy rates impact on the level of interbank interest rates; however, such effects can be easily be offset by the central bank through open market operations. Likewise, the pattern of declining interest rates during the day predicted by proposition 1 is unlikely to pose relevant problems; if it became pronounced, and were deemed undesirable from a policy viewpoint, it could be offset by

36 Several other options could be devised to deal with the externalities problem analyzed in Section 3. One could be to impose reserve requirements on the sending bank, proportional to the volume of payments processed. However, this policy would have a potentially large impact on banks' costs, which might induce them to seek cheaper and riskier alternatives to gross settlement. Alternatively, some form of peak-load pricing could be adopted, so as to penalize delayed settlement. A mechanism of this type is currently adopted on SIC.

the central bank through proper management of aggregate intraday liquidity. As pointed out by VanHoose (1991), changes in the rate charged by the central bank for daylight credit will have an impact on the volatility of interest rates on overnight and longer maturity loans. However, VanHoose finds that out of several policy options for the reduction of daylight overdrafts, charging a constant interest rate, as assumed in Section 3, is the least likely to cause increased volatility of market rates.

A different problem could materialize in systems that allow banks to overdraw if one or more banks failed to balance their position at the end of the day, resulting in substantial creation of excess liquidity. However, swift reaction by the central bank could minimize or avoid undesired effects on interest rates; in addition, besides the fact that these episodes should be seen as exceptional, an analogous emergency would likely yield similar consequences even if a netting system were used, given the primary role played by most central banks in the settlement phase of these systems.

5. Conclusion

The present paper has provided a formal analysis of some interbank payment arrangements whose implementation or enhancement is the subject of a growing debate among commercial banks, policy makers and academic economists; its main conclusions can be summarized as follows.

First, in gross settlement systems banks' demand for reserves and interbank loans will be small relative to a situation of social optimum, so that, other things equal, use of daylight credit will be relatively large. As a consequence, banks will tend to excessively postpone the input of payments and/or delay their settlement. Some new light is shed on the practice of delaying the input of payments (so-called "delayed sends"), which has thus far mainly been viewed as an efficient way to economize on the use of daylight credit. While not disputing this view, it is argued that delayed sends also have negative aspects: On the one hand, risk reduction via quick finality of payments is the main reason for the adoption of gross settlement, hence leaving banks with incentives to delay finality is contrary to the philosophy underlying the choice of these systems; on the other hand, payments delays will tend to add noise to the information contained in intraday balances, complicating banks' achievement of their planned end-of-day position and therefore reducing expected profits from payment processing activity.

These effects are due to a network externality rooted in the nature of gross settlement: Since for real-time payment processing liquidity is required, and reserves are costly to hold, each bank will tend to wait until some payments come in before sending out its own, so as to use other participants' reserves. These effects imply that, in the absence of corrective measures, the effectiveness of gross settlement systems for the reduction of risk in financial market transactions, which constitutes their main attractive, may potentially be impaired.

Finally, the paper formalizes the prediction made by several authors that if daylight liquidity is made available at a cost by the central bank a daylight market for funds is bound to arise, and generalizes it to the main models of gross settlement system; however, it shows that the creation of this intraday market per se is not sufficient to eliminate the externality problems mentioned above.

To this end, some corrective policy measures are discussed. A distinction is drawn between daylight liquidity and the traditional notion of liquidity, usually measured in terms of reserves held on settlement accounts at the end of the day. The analysis suggests that when the sending bank is charged for overdrafts the central bank, while safeguarding itself against credit risk, should provide daylight liquidity as inexpensive as possible, in order to reduce the mentioned network externality problems; in particular, wherever reserve requirements exist, banks should be allowed to use them at zero cost during the day for payment processing purposes. If the need to safeguard itself forces the central bank to set the cost of daylight liquidity relatively high, it is shown that elimination of network externalities can be achieved by appropriately splitting the charge for daylight credit used by the sender between the latter and the receiving bank.

The analysis suggests that adoption of gross settlement may increase the operational involvement of the central bank in the payments mechanism, and in some cases add new duties to the daily operation of monetary policy; however, it is unlikely to have a significant impact on the central bank's ability to control short-term interest rates. Indeed, adoption of new policy instruments, such as an interest rate on daylight repurchase agreements or a rate on daylight credit, can make the management of intraday liquidity independent of the mechanisms for the control of short-term interest rates traditionally employed by central banks.

Although the paper's focus is not on the choice between clearing and gross settlement systems, the empirical evidence presented seems to suggest that intermediate configurations (in particular queuing systems) are more efficient than the two alternative extreme options (pure gross settlement with no daylight overdrafts and pure netting without collateral). This situation calls for further research on the topic: the robustness of the latter conclusion requires empirical validation; at the theoretical level, further modeling effort is required to extend the analysis to the various existing types of netting systems. These extensions would prove extremely useful for the choices concerning payment system design currently facing policy makers and banks in several countries.

Appendix 1: Proof of the propositions

Proof of Proposition 1

Assume that $r_{b,1} \leq E_1(r_{b,2})$. We can distinguish two cases:

1.a) Suppose that the central bank performs no open market operations; substitution of (11) into (10) allows to check that $r_{d,1}\int_0^{k_1} dF(\mu_1^B | I_1) \leq 0$. Since the left-hand side of this inequality is nonnegative by construction, strict inequality cannot hold; it must therefore be $r_{d,1}\int_0^{k_1} dF(\mu_1^B | I_1) = 0$, which implies $k_1 \leq 0$, and from (12) $g_1 = 0$ i.e. $a_1^A = 0$; since a condition analogous to (12) must also hold for bank B, it must be $a_1^B = 0$ as well. Since $q_1 = 0$ due to lack of central bank intervention, recalling the expression for k_1 given in (9) I get $v_1 \geq \mu_1 - R_{t_0}$; an identical condition must hold for bank B. Imposing the market clearing condition $\sum_{i=A,B} v_1^i = 0$ I get $\sum_{i=A,B}(\mu_1^i - R_{t_0}^i) \leq 0$, a contradiction; this proves *i)*. Since $r_{d,1}\int_0^{k_1} dF(\mu_1^B | I_1) > 0$ must therefore hold, from (12) $g_1 < 0$, hence $a_1^i > 0$, which proves *ii)*.

1.b) Suppose that the central bank operates so as to fully meet commercial banks' demand for reserves; then a daylight repurchase agreement can be viewed as an additional choice variable available to banks. Minimization of (8) with respect to q_1 yields

(A1) $$r_{d,1}\int_0^{k_1} dF(\mu_1^B | I_1) = r_Q.$$

Substitution of this expression into (10) and (11) allows to check that $r_{b,1}>E_1(r_{b,2})$, which proves *i)*; (A1) also implies $k_1>0$ and hence from (12) $a_1^i>0$, which proves *ii)*.

If banks demand for daylight repurchase agreements is rationed, applying Kuhn-Tucker conditions to (A1) allows to check that the left hand side will be strictly greater than r_Q; thus, the same steps as under *1.b*) can be applied.

Proof of Proposition 2

From (10) and (11) follows that

(A2) $$r_{d,1}\int_0^{k_1^A} dF(\mu_1^B | I_1^A) = r_{b,1} - E(r_{b,2} | I_1^A).$$

An analogous condition will hold for bank **B**. Since $E(r_{b,2}|I_1^A) = E(r_{b,2}|I_1^B)$, substituting (A1) and the equivalent expression for bank **B** into (13) I get $g_1^A=0$, which implies $a^{Ac}=0$. The same reasoning will hold for bank **B**.

Proof of proposition 3

i) follows from the structure of the Hessian of problem (8) (see the Appendix 2): A reduction in a^i causes an increase in v_1; which in turn increases v_2. *ii)* and *iii)* follow directly by using result *i)* in (6) and (7).

<u>Proof of proposition 4 (sketch)</u>

At the end of the second period bank i chooses v_2 based on the conditional density $f(\hat{\mu}_2^i \mid y_1^i, \ldots)$, where y_1^i is given by equation (4) and $\hat{\mu}_2^i$ is defined as follows:

$$\hat{\mu}_p^i \equiv \sum_{t=1}^{p} \sum_{s \neq i} b_t^{si} \mu_t^s . \tag{A3}$$

Consider the conditional probability function $f^*(y_1^i \mid \hat{\mu}_2^i)$ over the space spanned by y_1^i; f^* defines the probability that the "signal" y_1^i will be observed for each realization of the "state of nature" $\hat{\mu}_2^i$. In the terminology of Laffont (1990), f^* is an information structure with noise. In the free-market equilibrium bank i, not knowing $a_1^s > 0$, observes a "noisy signal" for $\hat{\mu}_1^i$, $y_1^{im} \equiv \sum_{s \neq i} b_1^{si}(\mu_1^s - a_1^{sm})$. On the contrary, in a situation in which banks have no incentive to put off the input of payments $a_1^s = 0$, hence i observes exactly $y_1^{ic} \equiv \hat{\mu}_1^i$, which is a noiseless signal for itself. $f^*(y_1^{im} \mid \hat{\mu}_2^i)$ is therefore a "garbling" of $f^*(y_1^{ic} \mid \hat{\mu}_2^i)$. The proof of proposition 4 for the case of a discrete signal space follows directly from a corollary in Laffont (1990), chapter 4, p. 63. Blackwell (1951), (1953), shows that the result applies for the weaker assumption of a bounded signal space.

Note that for $n=2$ equations (10)-(12) yield: $-g_1^i(a_1^i, z_1^i) = r_{b,1} - E(r_{b,2} \mid I_1^i)$. Further, equation (4) simplifies to: $y_1^j = \mu_1^i - a_1^i$. Since y_1^i is observable, these two expressions yield an equation in which a_1^i is the only unknown from bank j's viewpoint, and can therefore be retrieved along with μ_1^i. Hence proposition 4 does not hold.

Proof of proposition 5

Recalling that $-|g_1|=g_1$, *i)* follows by applying Kuhn-Tucker inequalities to equation (12); *ii)* follows by applying Kuhn-Tucker conditions to equations (12) and (A1).

Appendix 2: Second order conditions for problem (8)

The Hessian of problem (8) is the following:

$$\begin{bmatrix} -r_{d,1}f(k_1)-r_{d,2}\bar{f}(k_2) & -r_{d,2}\bar{f}(k_2) & -r_{d,1}f(k_1) \\ & -r_{d,2}\bar{f}(k_2) & 0 \\ & & -r_{d,1}f(k_1)+g_{11} \end{bmatrix}$$

where the differentiation is taken in the same order as for the first order conditions (10)-(12). It is straightforward to check that the sufficient conditions for a maximum are satisfied.

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