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Why pay? An introduction to payments economics ☆

Charles M. Kahn [a], William Roberds [b,*]

[a] Department of Finance, University of Illinois, USA
[b] Research Department, Federal Reserve Bank of Atlanta, USA

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ABSTRACT

This paper surveys the growing literature on payments. We begin by presenting a simple model that illustrates the essential function of payments and how this may be implemented through various arrangements. We show how the basic models of payments have been used to address a variety of microeconomic and macroeconomic policy issues. We then discuss the links between payments economics and other fields, including monetary theory, corporate finance, and industrial organization. We conclude with an overview of the empirical literature and directions for future research.

1. Introduction

Payment systems are the plumbing of the economy—a collection of conduits that is essential, pervasive, and boring (until there's a malfunction). Economists studying payment systems have long labored under the shadow of this unsavory metaphor. Recently, however, payments economics has begun to achieve some respect, because of the significant changes in payments technology and infrastructure, because of the important policy concerns associated with the industry, and possibly because of the sheer magnitude of payment activity.

☆ The views expressed in this paper are those of the authors and not necessarily those of the Federal Reserve Bank of Atlanta or the Federal Reserve System. An earlier version of this essay was presented by the first author at a conference, "The Economics of Payments II" held at the Federal Reserve Bank of New York, March 29–30, 2006. We thank participants in that conference and in seminars at the Bank of England for valuable comments.

* Corresponding author.
E-mail addresses: c-kahn@uiuc.edu (C.M. Kahn), william.roberds@atl.frb.org (W. Roberds).

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A payment occurs when one economic agent transfers value to another agent for the purpose of discharging a debt. In developed economies, the action of payment is so mundane and apparently simple that a definition hardly seems necessary. But economists have struggled to understand the nature of this everyday activity: constructing a convincing microeconomic model of payments is a challenging task. Payments and payment systems, so ubiquitous and obviously essential to real-world economies, are conspicuously absent from the world of Arrow–Debreu.

But what precisely are the frictions that give rise to payment arrangements? Do these frictions, and the payment systems designed to overcome them, matter for economic allocations more generally? How do payment systems interact with the machinery of financial intermediation and macroeconomic policy? And how will these systems evolve with the ongoing improvements in information technology?

This essay is an (admittedly idiosyncratic) introduction to some of the policy issues dealt with by payments economics and to some of the empirical work on payment systems, but above all to the models used to understand the role of payments in an economy and the forms which payments take. The first generations of models of payment systems have been valuable in informing certain policy debates, for example within central banks on payment system design and stability. Recent improvements in the microfoundations of these models will broaden their relevance, not only to issues in banking and financial intermediation, but also to economic history, macroeconomics, and industrial organization. By the end we hope the reader will conclude that plumbing can be an interesting, as well as important, object of study.

The plan for this paper is as follows: The remainder of this introduction documents the magnitude and growth of the payments industry and outlines the important policy questions at both wholesale and retail levels.

The next two sections outline a basic theory of payment and describe various extensions. While the discussion ranges over a broad spectrum of arrangements and models, the general direction is from abstract to concrete. We argue that the fundamental imperfections which give rise to payments are a time mismatch in consumption, and imperfect enforcement of credit arrangements. Section 2 introduces the basic model and the two fundamental types of payments arrangements: accounts systems and store-of-value systems. It discusses the relative advantages of each, and the briefly considers factors involved in an apparent move over recent times away from store-of-value towards accounts based systems.

Section 3 discusses "hybrid payments arrangements" intermediate between the two fundamental types. The most important example is transferable debt, also known as "inside money" in the monetary theory literature. We review some models of inside money, showing how the payments approach provides a fresh perspective—highlighting the evidentiary role of transferable debt, potential links to corporate finance, and insights on netting arrangements in securities settlement.

Sections 4 and 5 review in greater detail the studies of payment systems in light of the two fundamental policy issues linked to them: one macroeconomic—how do payment systems affect monetary policy—and one microeconomic—what, if any, are the market failures associated with privately-run payment systems. Section 6 reviews the still small but rapidly growing empirical literature on payments.

1.1. Payments—big business and getting bigger

Payments are big business, even by the standards of macroeconomists. For example, 89 billion payments of $937 trillion were recorded in the United States in 2005, not counting payments made in currency.[1] This figure corresponds to about $75 in payments for each dollar of GDP, a ratio that has

[1] This figure does not include the U.S. dollar payments made through the international, multicurrency CLS system, which were likely in excess of $1 trillion a day in 2005 (no precise figures are available). Adding these in would drive the annual total to well over $1 quadrillion.

been steadily rising over time. Payment statistics in all developed economies display similar levels and trends (summary statistics can be found in Committee on Payment and Settlement Systems, 2007).[2]

Much of the recent pickup in payments activity comes from the *large-value* or *wholesale* payment systems used to settle obligations between banks. Since the "funds side" of financial market trades[3] must ultimately settle through such systems, volume over these systems has mushroomed with the upsurge in financial market trading.[4] But volume is also expanding quite rapidly over certain types of *small-value* or *retail* payment systems, those used by households and nonbank firms. In the U.S., for example, usage of debit cards and direct transfers[5] is expanding at double-digit rates (measured either in terms of the volume or value of transactions), even as the usage of checks and cash is declining (Humphrey, 2004; Gerdes et al., 2005; Garcia-Swartz et al., 2006a; Klee, 2006a). Transactions that were once only conducted solely with cash are increasingly made using cards that electronically link buyers to their payment histories.[6]

The past decade has also witnessed tremendous innovation in payments. Besides the spectacular rise of card payments, innovative web-based payment systems such as PayPal have enabled individuals to "wire" funds across great distance, instantaneously and at low cost (Kuttner and McAndrews, 2001). At the wholesale level, the multicurrency CLS system (beginning operations in 2002) has allowed banks to coordinate the settlement of foreign-exchange transactions across national borders, binding together all major national payment systems in a way that was unthinkable a decade ago. And there is no reason to believe that the rate of innovation will slow down anytime soon. The "payment card" of the future will likely be just a "smart card," cell phone, or other portable computing device, able to instantaneously transfer value to anyone so equipped.[7]

1.2. Policy issues

While the technology-fueled expansion of payments activity has clearly generated tremendous economic benefits, it has also generated noteworthy and in many cases, unresolved questions for policymakers.

Important policy issues for wholesale payment systems include *access*, *liquidity*, and *systemic risk*. Important policy issues for retail payment systems include *competition* and *fraud*. *Cross-border coordination* is an important problem at both levels.

1.2.1. Wholesale systems

Economic models of banks have usually focused on the roles of banks as financial intermediaries, parties able to exploit the synergies between the provision of extremely liquid deposits and illiquid loans (e.g., Diamond and Dybvig, 1983; Kashyap et al., 2002). But banks have always served another, equally essential role, as providers of payment services—as parties able to transfer liquid claims quickly and cheaply and with a minimum of legal uncertainty.[8]

2 *Net* payment flows are markedly less than the numbers cited above, on the order of one percent of gross flows. But we would argue that what is critical for the integrity of every payment system is the control of gross exposures that arise through its associated payment flows. This view is well supported by various accounts of payment system disruptions during periods of market duress (see for example Committee on Payment and Settlement Systems, 1996; McAndrews and Potter, 2002).

3 Residual amounts left after any netting of securities trades.

4 In fact there is a close connection between the study of payment system and the study of clearing and settlement systems for financial markets. See the discussion in Section 3.1 below.

5 I.e., those made through the Automated Clearinghouse (ACH), such as direct deposit of payrolls.

6 For a valuable examination of the history and growth of the use of credit cards see Evans and Schmalensee (1999); an informal theory of the process is found in Kahn (2006).

7 Although in the case of smart cards, it probably makes sense to be a little cautious. Observers have for many years been predicting their arrival as a major payment method. While they have begun to have an impact in other countries, they still are relatively unused in the U.S.

8 Accounts of the early history of banking (see Kohn, 1999 for a survey) indicate that banks arose first as providers of payment services—moneychanging and book-entry payments—and then diversified into the business of financial intermediation. Central bank participation in payment arrangements dates to at least the 15th century *Banco di San Giorgio* in Genoa (Fratianni and Spinelli, 2006). By the 18th century, book-entry payments at the Bank of Amsterdam—the leading central bank of its day—were

Financial innovations such as securitization, syndication, and credit insurance have eroded banks' advantages as financial intermediaries, subjecting them to competition from both financial markets and nonbank financial institutions. But, for the moment at least, banks continue to enjoy significant advantages over nonbanks as payment service providers. These advantages include, most critically, full *access* to wholesale payment systems. Such access is usually restricted to (regulated) banks, and sometimes only to banks whose home charter is in the same jurisdiction as the system itself.[9] Indeed it has been argued that such access has become *the* definitive feature of a bank (Lacker, 2006). Recent policy discussions in the U.S. regarding the acquisition of banks by nonfinancial firms have focused on this issue. Wal-Mart and other would-be acquirers of banks have stated that their principal motivation is not to compete with banks as financial intermediaries, but instead to gain unfettered access to interbank payment arrangements.[10]

Liquidity is a concern because of the very high value of payments routed through wholesale systems. No intraday markets exist to allocate this liquidity. Instead, such liquidity has traditionally been allocated implicitly through agreements between banks to settle payments on a net basis. During the 1990's, however, net settlement of large-value interbank payments came under criticism as being vulnerable to *systemic risk*, roughly defined as the risk that a failure by one bank to settle might result in multiple settlement failures.[11] Chains of failures have rarely been observed in practice, but there have been enough "near misses" to produce considerable regulatory angst.[12] Consequently net settlement has in many cases been abandoned in favor of *real-time gross settlement* (RTGS).

In an RTGS system,[13] each payment by a bank to another bank consists of an irrevocable transfer of central bank funds—in the U.S., for example, between reserve accounts with the Federal Reserve Bank. Until the payer has access to such funds, no payment can be made. RTGS systems thus insulate an individual payee from systemic risk, but their operation requires many times more central bank liquidity than operation of net settlement systems. How such liquidity should best be provided remains an open question. The Federal Reserve System, for example, routinely allows banks using Fedwire to incur uncollateralized intraday overdrafts, but other central banks (Euro area, Japan, UK) only grant such credit against collateral. The Fed charges fees against overdrafts (over a ceiling), but many other central banks do not. Other large-value payment systems—CHIPS in the U.S., LTVS in Canada, and the multicurrency CLS—have opted for arrangements that employ modified versions of net settlement, often in conjunction with queuing arrangements that attempt to optimize the extent to which queued payments may be netted (Intraday Liquidity Management Task Force, 2000; McAndrews and Trundle, 2001; Willison, 2005). The right price for liquidity, taking into account system-wide safety concerns and bank incentives, is a fundamental issue for both private and public systems.

1.2.2. Retail systems

For retail systems, the principal policy controversies have centered on issues of competitive efficiency. Payment systems are a relatively expensive component of financial infrastructure, as much as 3 percent of GDP in the U.S. (Humphrey et al., 2000). In the U.S. case, one reason this figure is so high is the continued widespread use of checks, but the cost of electronic alternatives can also be substantial, particularly for card-based payments. Merchant dissatisfaction with the fees charged for card payments has resulted in some spectacular antitrust litigation in the U.S. (the "Wal-Mart case"

the dominant wholesale payment system in Europe (Quinn and Roberds, 2006). For a reexamination of banking history from the point of view of payment systems, see Speight et al. (2006).

[9] A condition for full participation in such systems is an account with the relevant central bank, even in cases where the system is privately operated. Central banks have traditionally limited access to such accounts, justifying this limitation both on moral hazard grounds (Bank of England, 2002), and on a reluctance to compete with commercial banks (Green and Todd, 2001).

[10] See for example the written testimony of Jane J. Thompson, Wal-Mart Financial Services, at the Wal-Mart Bank Federal Deposit Insurance Application Public Hearing, April 10th, 2006, Washington, DC. Available online at http://www.fdic.gov/regulations/laws/walmart/publichearings/walmartjane.html.

[11] See the "Lamfalussy report" (Committee on Payment and Settlement Systems, 1990).

[12] Two of the most famous occurrences resulted from the 1974 failure of Bankhaus Herstatt and the 1991 failure of BCCI; see the "Allsopp report" (Committee on Payment and Settlement Systems, 1996) for the details of these and other incidents.

[13] Including Fedwire in the U.S., TARGET in the Euro area, BOJ-NET in Japan, CHAPS in the UK, and many others.

against Visa and MasterCard, settled in 2003 for $3 billion; additional lawsuits are pending) and outright regulation of card fees in countries such as Australia (Lowe, 2005). As is the case with some other "network" industries, there is little consensus on what constitutes an efficient fee structure for card-based payments (Rochet and Tirole, 2006a).

Another policy controversy associated with retail payments has been the emergence of new forms of payments fraud such as "identity theft." Electronic payment systems can offer tremendous efficiency gains, by allowing for rapid and easy transmission of information across system participants. But the flipside of this efficiency is that these same systems can allow for rapid propagation of fraud. A single loss of confidential data, such as the compromise of 40 million credit card accounts at CardSystems Solutions Inc. in June 2005, can lead to significant fraud losses.[14] Payment service providers and policymakers have struggled to find a balance between the inherent advantages of information-sharing, and the potential costs that can arise due to fraud and loss of privacy.

Payment systems have traditionally observed national boundaries, but over the past decade cross-border arrangements have become increasingly common. Cross-border credit card and ATM card transactions are now routine, and cross-border direct (ACH) transfers are starting to see increased usage. At the wholesale level, the Euro-area-wide TARGET system (beginning operations in 1999) and the multicurrency CLS system are now the world's two largest payment systems, measured by the value of funds transferred. The advent of these cross-border arrangements has no doubt facilitated international commerce, but at the same time their operation has raised the spectre of risk from mismatch of systems and regulations combined with greater potentials for participants to exploit cross-border incompatibilities. Addressing these concerns has required a much greater degree of co-ordination among central banks and regulatory authorities than was previously the case.

2. Theory of payments

Payments arise in environments characterized by two potential impediments to exchange: a *time mismatch* of trading demands, and *limited enforcement* of pledges about future behavior.

The notion of a time mismatch is less stringent that Menger's celebrated "lack of double coincidence of wants." What is key is not an absence of counterparty-by-counterparty matchups in consumption good demands, but instead an inadequate supply of liquid (desirable) assets to allow for exchange to proceed as a sequence of spot trades.

Limited enforcement can arise in many ways. Enforcement of obligations might be hindered by geographical displacement of potential transactors, or by an inadequate legal system. Informational frictions can also play a role: For example, account-based payment systems must incorporate at least two critical information technologies—one for keeping track of an individual's actions over time, and another to verify identities. The scope and application of such systems is clearly limited by the efficiency of these underlying technologies.

Broadly defined, a *payment system* is any arrangement that enables exchange by overcoming the paired frictions of time mismatch and limited enforcement; payments economics is the study of such arrangements. As such, this field has drawn on many fields of economics, but as noted by Green (2004), its most important antecedent is monetary theory. The study of payments is in part a study of the techniques institutions use to increase transactions velocity, i.e., to make payments more efficiently with the same stock of money (see, for example, Temzelides and Williamson, 2001).

Despite its overlap with monetary economics, the study of payments is focused on very different issues from the study of money. Monetary theory focuses on questions about how money obtains its value, the relationship between inside and outside money, and how the supply of money should be optimally regulated. Payment economics is in a sense more fundamental, relying on information economics and mechanism design to characterize alternatives to money, and to explain how certain assets may take on money-like traits. Over the long run, changes in underlying features of economic environments and consequent structure of payments will continue to redefine what may be considered "money."

[14] See Isabelle Lindenmayer, "Security Watch," American Banker, Friday, September 2, 2005.

In discussing payments systems, we will focus on the distinction between *store-of-value systems* and *account-based systems*. Store-of-value systems, such as commodity money, fiat money, and stored value cards, are founded on the transfer of some payments object (be it coins, notes, or electronic stored value) between payer and payee, and they depend critically on a payee's ability to verify the payments object. Account-based systems, such as charge accounts, checks, and credit cards, require the keeping of accounts in the name of the payer and payee. The success of account-based system hinges, most fundamentally, on the ability of its participants to verify the identities of account holders, to ascertain the link between transactors and histories. This dichotomy necessarily represents something of an idealization, and there are some important types of systems (e.g., debit cards) that arguably do not fall so neatly into either of these camps. Nonetheless most payments arrangements develop from one of these two forms. Understanding why this should be so remains an interesting challenge (first posed by Green, 2004) for the theory of payments.

For each of these types of system we first consider a "Platonic ideal"—a baseline model of how such a system might function in its most unfettered form. For account-based systems this ideal is pure, costless credit. For store-of-value systems it is spot trades using perfectly liquid assets. When considering more complex systems, we will treat them as attempts to approximate one of these two ideals (for a similar approach, see Nosal and Rocheteau, 2006).

2.1. Model framework

We illustrate the payment systems we describe in terms of a very simple framework. Suppose that a finite set of risk-neutral agents $\{1, \ldots, N\}$ are arranged in a ring. Each agent only desires the good produced by the agent located K places further along the circle and only at certain times. Specifically, in periods $1, N+1, 2N+1, \ldots$, agent 1 desires agent $K+1$'s production; in periods $2, N+2, 2N+2, \ldots$, agent 2 desires agent $K+2$'s production and so forth. A unit of desirable consumption is worth X to the agent receiving it and costs $Y < X$ to the agent producing it. The discount factor per period is $D^{1/N} < 1$ (so that each subsequent consumption opportunity by an agent is worth the fraction D times the preceding one).

The case of $N = 2$ is bilateral exchange. The case of $N = 3$, the intertemporal Wicksell triangle, consists of two subcases $K = 1$ and $K = 2$. In $K = 2$, the desired pattern over time for each agent is "..., produce, rest, consume, produce, rest consume ..." This is the pattern used in Kahn and Roberds (2007), for example. In $K = 1$, the desired pattern over time for each agent is "..., produce, consume, rest, produce, consume, rest, ..." This is the pattern used in Kiyotaki and Wright (1989) for example. In general the pattern is

"... produce, rest $K-1$ periods, consume, rest $N-K-1$ periods, ..."

We will see the significance of varying the length of the two rest intervals in subsequent sections. For simplicity we will only deal with cases where N is prime.[15]

2.2. Baseline 1: pure credit

Theoretical models of exchange often examine "gift-giving" equilibria, but of course economic agents never give gifts selflessly. Instead successful gift-giving arrangements entail agents' giving gifts in anticipation of future rewards, possibly combined with fear of punishment if gifts are not handed over. Gift-giving arrangements are thus more likely to be successful given a sufficiently low discount rate, high anticipated future benefits, high probabilities of observing supplier behavior, and stringent penalties for defection. A classic example of gift giving arises in Diamond's (1990) model of pairwise meetings with credit, where autarky is the punishment. Jin and Temzelides (2004) extend this idea in their study of the interactions of money and credit. In their model, the frequency of meetings between agents determines the possibility of credit relationships. Agents simultaneously maintain credit relationships with individuals with whom they meet frequently, and cash relationships with individuals whom they rarely meet.

[15] If N is prime, then, no matter what value K takes, all members of the economy are ultimately connected through supply relationships. If $\mathrm{lcd}(K, N)$ is greater than 1, then in effect the economy is split into $\mathrm{lcd}(K, N)$ smaller noninteracting economies.

In pure credit models, retaliation against defectors can take a variety of forms. One obvious possibility is a fine or nonpecuniary punishment ("jail"). Others include an individual refusal to trade, expulsion from a group, or even "the nuclear option"—economy-wide reversion to autarky.

In our model, let us suppose that a failure by one agent to deliver goods when expected is detected by other agents with a probability G (and always detected by the agent not receiving the good). Let us suppose that the only punishment available is the nuclear option. If $G = 1$, then a credit arrangement (one in which each individual in the circle is expected to supply to the appropriate agent at appropriate times) is feasible as long as

$$XD^{K/N} \geqslant Y \tag{1}$$

for then the cost of not supplying in terms of subsequent breakdown of trade is greater than the savings in production cost.

In these highly stylized models of exchange, gift giving can be surprisingly robust. Araujo (2004) shows that gift-giving equilibria can be supported even if the identity of a defector is *not* known and acts of defection are *not* publicly revealed, as long as agents are sufficiently patient. Through a "contagion equilibrium," even a single refusal to trade can eventually lead to an economy-wide breakdown in reciprocity; thus agents are induced to adhere to the "social norm" of trade. If, in our previous example, G is 0 then the credit arrangement can still be supported provided that

$$XD^{K-1}D^{K/N} \geqslant Y.\text{[16]} \tag{2}$$

Although Araujo's result provides a useful theoretical starting point, it is clear that in general much less patience is required when defectors can be identified and punishments more sharply focused.

2.3. Credit with "hostages"

When credit is inadequate by itself, other institutions can arise to help support promises. These institutions allow, in effect, for the taking of hostages: agents agree on a (possibly costly) action making retaliation for defection easier or more potent.

Corbae and Ritter (2004) provide one example of such an arrangement where, in addition to the possibility of interacting in random meetings, agents can form partnerships that extend voluntarily over time. The message in their paper is that even if an individual is currently matched with a less-than-ideal partner, the continuation of the partnership can enforce promises by enhancing the cost of defection.

In the context of payments, a more typical form of hostage is *collateral*. There are numerous examples of models where collateral effects payment. In Shi (1996) and Li (2001) collateral is modeled as the taking of an agent's "tools" until a debt is repaid. The absence of the necessary implements makes consumption impossible. Koeppl and Monnet (2006) construct a model of central counterparties and margin posting, whereby payments are facilitated by collateral held in escrow by a third party. Kahn and Roberds (2001a) place a similar interpretation on the CLS system for international large value payments. They argue that CLS acts as an "escrow agent" able to impose greater penalties for nonperformance than could be imposed through purely bilateral arrangements.

Such arrangements depend on the ready availability of a suitable collateral good, one for which there is a low cost of transfer into the creditor's control (low transportation costs, low likelihood of damage while hostage, no legal uncertainty about ownership). The cost to the debtor from loss of the collateral should be high relative to its value to the creditor (Williamson, 1985). Collateral also tends

[16] The intuition for condition (2) is as follows: In the contagion equilibrium, an agent, once cheated on, never supplies again. Non-cooperation spreads through the economy at a speed dependent on the length of time the individual waits between consumption and production. If $K = 1$, so that each agent supplies the next around the circle, then what goes around comes around very quickly—the bad news travels so fast that the offending agent never gets to consume after defecting. In this case, a contagion equilibrium is as effective as public observability. On the other hand, if $K = N - 1$ so that each agent supplies to the agent *behind* him, then it takes nearly a period for agent N to inform agent $N - 1$ of agent 1's defection, and nearly another period for the news to pass to agent $N - 2$, and so on around the circle until $N - 2$ periods have passed before agent 2 stops supplying to agent 1.

to reduce costs of keeping track of a debtor, since the debtor has an incentive to return to retake possession of the collateral.

In our previous example, suppose that in the economy are N different types of assets. Each asset provides a specific agent a constant, continuous utility flow. Let H be the capitalized value of this consumption flow per unit, so that $H(1 - D^{1/N})$ is the agent's utility from holding one unit one period. There is zero cost to transporting the assets and no decay associated with them. These assets provide no utility to any agent other than the agent with whom they are associated; thus if held by anyone other than the associated agent, the utility that period is lost.

Suppose that in order to receive the consumption in his appropriate period an agent surrenders some of the asset (for simplicity to a central authority) and only receives it back when he has produced for another agent. In this respect posting collateral imposes an opportunity cost, but it may enable the agents to trade successfully.

For this scheme to be successful, the following two conditions must hold:

$$XD^{K/N} - Y + H\left(1 - D^{K/N}\right) \geqslant 0,$$

that is, the agent must find it profitable to produce today, in return for receiving consumption good K periods hence and retaining his collateral in the meanwhile.

$$X - YD^{(N-K)/N} + HD^{(N-K)/N} \geqslant H,$$

that is, giving up the collateral today in return for consumption today (plus the return of the collateral when production occurs) beats retaining the collateral today. This second condition always holds, provided the first condition holds.

Essentially there are two cases to consider. Under inequality (1), collateral is unnecessary; trade under public information can proceed without it.[17] If (1) does not hold, then the minimum value of the collateral needed for an agent to sustain trade is

$$\left(Y - XD^{K/N}\right)/\left(1 - D^{K/N}\right).$$

In steady state, the gain from each trade is $X - Y$. The social cost for each trade, in terms of collateral whose use is foregone is $H(1 - D^{(N-K)/N})$. In particular, if $K > N/2$ the steady state social costs from using the minimum necessary collateral are always less than the benefits from the trade. In this case, if pure credit arrangements are not feasible, it is always valuable to adopt a collateral scheme, provided enough collateral is available. However, this ignores the startup costs of the scheme. For the first K agents have no incentive to join the scheme, since they start by supplying goods without receiving anything in return. Thus the collateral arrangement will also bear the costs of "priming the pump": encouraging the first K producers to join the scheme.

2.4. Baseline 2: pure spot exchange

From hostage taking it is a small jump to spot trades in assets. Hostage taking occurs when a creditor does not value an asset posted as collateral, but anticipates that he original owner will pay to get it back. Trading in assets occurs when the "hostage" collateral good can be readily sold to third parties, so that accepting such a good in payment makes sense, even if the payee does not value the asset itself. In this sense, commodity money is simply an asset with a negligible cost of transfer (Ostroy and Starr, 1974; Kiyotaki and Wright, 1989). At some point there is no longer the need to maintain accounts and the transferred asset becomes a "store of value."

Models with store-of-value payments often place agents into "wilderness" settings. An agent wanders about ("searches") through an uncharted rain forest, occasionally encountering a lone stranger. These encounters are never repeated, and agents are beyond the reach of any court. The only feasible interactions between agents are spot trades: each agent simultaneously holds out his own good while

[17] If (1) holds but trades are not public information, then infinitesimal amounts of collateral would be useful simply as evidence that trades have occurred. This fact somewhat anticipates the discussion of models of fiat money below.

grabbing for the other. Absent a double coincidence of wants, goods can only trade for a store of value.

Working through the models of these environments is valuable for emphasizing the parsimony of information needed to effect payment under a store-of-value system. A trader needs to verify the genuineness of the proffered store of value, but need know nothing about his counterparty.[18]

The canonical model of this type is the well-known search model of Kiyotaki and Wright (1989). But the essential idea of nonrecurring encounters can be found in earlier models such as Samuelson's (1958) overlapping-generations model and Townsend's (1980) turnpike model. "Island" models such as Freeman (1996) motivate the use of money through both overlapping generations and geographic dispersion. "Day/night" models such as Lagos and Wright (2005) have increased the tractability of search models by allowing for alternating periods of anonymous trade and trade in Walrasian markets.[19]

The ingenious details of these models can sometimes obscure their key point, which is that trade in assets is useful if malefactors cannot be identified, caught, and punished. In other words, a market could be completely centralized, but if it were also completely anonymous, trade in stores of value will still be useful.

In our example suppose there is a fixed supply of a storable, transferable and divisible asset which gives a continuous stream of value to *any* individual (call it "gold jewelry").[20] Again, let H represent the capitalized value of the consumption stream of a unit of the asset. When in the form of jewelry, the gold content is not easily determined, thus the jewelry cannot be used as a hostage. However, it can be costlessly melted down to a generally recognized form. When in this "monetary" form, however, it has no use as jewelry, and recasting it requires T periods.

The question then is whether trade can be supported by exchanging monetary gold for goods at each period, and if so, what are the costs associated with the arrangement.

A producer's steady state incentive condition is as follows:

$$XD^{K/N} - Y + H\big(D^{T/N} - D^{K/N}\big) \geqslant 0.$$

In words, a producer will receive consumption K periods from now. In the meanwhile he will hold the gold, but it will take T periods before utility can be derived from it. (Note therefore that if $T > K$, gold cannot serve as commodity money.)

The conditions for the consumer are

$$X - YD^{(N-K)/N} - H\big(1 - D^{(N-K+T)/N}\big) \geqslant 0.$$

Again the producers' condition implies the consumers' condition. Because of the posited cost of transforming the gold back to jewelry, it takes more commodity money by value to achieve the trades than it takes collateral. However, the social cost of using commodity money can be less, since it can be enjoyed by the recipient after T periods, where the collateral cannot be enjoyed until it is returned to the owner. If there were no time cost to transforming the commodity, then there would be no social cost in its use as money.

A second important difference between collateral and commodity money arises at the beginning of the economy: in the case of commodity money there is no need to "prime the pump." The incentives of the initial producers are also in line since they receive value for their production initially. In any case, introducing commodity money potentially relaxes the constraints imposed by credit arrangements.

2.5. Fiat money as a store of value

Any good with the necessary physical characteristics can serve as a store of value. But if such assets are in short supply, one possibility is to create them in the form of fiat money. There are

[18] A potential problem with these models is how to enforce spot trades, i.e., how to keep anonymous, isolated spot trades from degenerating into swindles or simple robbery.

[19] For a comprehensive survey of search models of money see Wright (2008).

[20] This account of commodity money follows that of Velde and Weber (2000).

numerous theories about how intrinsically worthless fiat money may come to represent a store of value, but these can generally be split into two groups. The first group—the “Peter Pan theories”[21]—postulate that money has value today because it is believed to have value tomorrow (see references in the previous section). The other group—the “Mahagonny theories”[22]—assert that money has value because it is needed to pay taxes (as in e.g., Starr, 1974; Aiyagari and Wallace, 1997). From the point of view of payments foundations, it does not really matter which group of theories is the more accurate. Once the money has future value, for whatever reason, it can function as a store of value.

Let us consider the introduction of fiat money into our simple model. Following the tradition of the money search literature, let us imagine that each of the K initial consumers is endowed with 1 unit of fiat money, which he uses to pay for his purchases. These units of fiat money then circulate in the opposite direction of the flow of goods in the economy. Let $V(1)$ be the utility of a consumer who holds a unit of fiat money at the time of his consumption. Let $V(0)$ be the utility of a producer who holds no fiat money at the time of production. Then

$$V(0) = -Y + D^{K/N} V(1),$$
$$V(1) = X + D^{(N-K)/N} V(0)$$

whence

$$V(0) = (1-D)^{-1}\left(D^{K/N} Y - X\right),$$
$$V(1) = (1-D)^{-1}\left(X - D^{(N-K)/N} Y\right).$$

Trade will be sustained with fiat money if $V(0) \geqslant 0$, which is the same as (1). In other words, fiat money can be used to decentralize trade in situations where full information credit arrangements are also viable, but in our account, unlike commodity money, fiat money does not extend the set of environments in which trade takes place under full information.

2.6. Comparing credit and store-of-value arrangements

When trade based on credit fails or is too costly due to limited enforcement, then trade in assets, including fiat money, may be an attractive alternative, imposing fewer informational and enforcement costs. Numerous papers (e.g., Townsend, 1987; Taub, 1994; Aiyagari and Williamson, 2000; Corbae et al., 2003; Berentsen et al., 2007) have shown that, in some circumstances at least, trade with money can deliver identical outcomes to trade with credit. Kocherlakota (1998) argues that this is because money functions as a cheap, easily transportable proxy for expensive public record keeping (“memory”), i.e., an agent’s money holdings can effectively serve as a sort of portable account balance.

But payment in money, like all store-of-value arrangements, is inherently a little less flexible than recordkeeping, because it is subject to a physical restriction in various stochastic realizations (as anyone who has ever searched for an ATM can attest). A strand of the literature emphasizes this distinction (Kocherlakota and Wallace, 1998), implying that as the costs of recordkeeping fall, the use of payment systems based on store of value should likewise fall. Temzelides and Yu (2004) develop this idea in a model in which money is used when it is not worthwhile to track credits and debts in more complex ways: small transactions use money.

In practice, of course, store-of-value systems can lead to their own informational and enforcement frictions. Counterfeiting, virtually eradicated in the developed world, is much more prevalent in developing countries (Judson and Porter, 2003). The limited information associated with cash leads to its use in payment for illegal activities (Camera, 2001). In turn, the use of cash is limited by its susceptibility to theft; account-based systems are, in this respect, the safer alternative (He et al., 2005).

Over time, society can (and does) create alternative types of payment infrastructures. Specifically it can develop better courts, better surveillance techniques and communication systems, better ways

[21] According to J.M. Barrie’s 1904 play, fairies only survive as long as children believe in them.

[22] After the 1930 Brecht/Weill musical *Rise and Fall of the City of Mahagonny*, which takes place in a city where the only crime is to be caught without money.

of identifying people, and better recordkeeping. All of these increase the costs of nonadherence in account-based systems. As a result, over the past century, the margin where account-based payment systems become effective has grown ever smaller.[23]

3. Hybrid payment systems: transferable debt

Most actual payment systems incorporate features from the two basic models outlined above. An idea common to all of these hybrid arrangements[24] is the use of privately issued, transferable debt (inside money) in one form or another. We can think of this debt as privately-, rather than publicly-issued pieces of paper (although nowadays they are more likely to take some electronic form). These pieces of paper derive their value from the issuer's credible promise to redeem them. Through the use of transferable debt, one person's credit (on account) becomes another's means of payment (store of value). Both sorts of verification will be necessary for a successful transferable debt: a payee needs to verify that a note is what it claims to be, and to verify that the issuer is good for it.

Papers such as Cavalcanti and Wallace (1999), Williamson (1999), Kiyotaki and Moore (2000), and Andolfatto and Nosal (2003) investigate a basic model of inside money. In this framework, only certain agents are able to transact for credit, because they possess some special advantage as reliable debtors—they are easy to locate, famous, or just unusually upstanding individuals. These agents function as bankers. Other agents cannot borrow on their own recognizance, but must use whatever store-of-value payment mechanisms are available: real assets or outside money. If these are in limited supply, then adding bankers' transferable debt to the set of alternatives extends the economy's payment capacity. In Williamson (1999) and Kiyotaki and Moore (2000) bankers are superior creditors as well, allowing them to hold illiquid claims while simultaneously issuing liquid debt; in short, bankers are engaged in the task of "liquidity transformation." In these models, separation between own-debt payers and inside-money payers is strict. In other words, no one in these models ever uses a debt to pay a debt, in marked contrast to the arrangements we observe in practice. Kahn and Roberds (2007) give an expanded model of transferable debt in which agents move at various times from one category to another. The move is occasioned by the mix of assets currently held by the agent (think of the conversion of raw materials to finished product over a production cycle). In this world it becomes useful to pay outstanding debts with other forms of debt, thereby enabling the removal of agents from a "credit chain" (Kiyotaki and Moore, 1997) in a timely fashion.

This alternative approach to inside money is potentially important for understanding the role of liquidity in firms. In the corporate finance literature, there has been recently been a renewed interest in the precautionary demand for liquidity, and the determinants of a firm's cash holdings (Opler et al., 1999; Kim et al., 1998; Almeida et al., 2004).[25] Focus has centered on the decisions to raise liquidity by foregoing investment projects or engaging in external finance. But the timing of payment is one more method by which a firm adjusts its financial portfolio—the act of payment is a reordering of the seniority of its liabilities. Thus, timing of payments is another means of liquidity management. In order to build a credible model of the timing of payments by financial institutions, and the costs and benefits of delay, an account of payment as settlement of debt is necessary.[26]

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[23] The cost to a merchant of accepting card payments remains stubbornly high, in the U.S. about $.60 for a small ($11.52) grocery store transaction according to Garcia-Swartz et al. (2006a), while the same transaction in cash would cost the merchant only $.30. They argue that cards have become more competitive for small transactions, when one takes into account consumers' costs of acquiring and carrying cash, as well as the benefits of paying by card.

[24] Our use of the term "hybrid" as a combination of store-of-value and account-based systems, is in contrast to the policy literature, where the term "hybrid" is used to describe wholesale payment features that combine features of gross and net settlement (Willison, 2005).

[25] This interest has been reinforced by recent macroeconomic concerns over the "liquidity crunch."

[26] Bullard and Smith (2003) present another model of the usefulness of inside money. In their account, inside money economizes on transportation costs. It costs more to move bullion than to move paper. Suppose a chain of debts needs resolution, and suppose that this chain wanders off temporarily into Frontierland, before returning to an ultimate creditor who is in proximity to the ultimate debtor. Better to send a lightweight store of value following the path, and let the gold move the short distance to make final settlement of the chain. In other words, geographical separation can also make transferable debt valuable. Transportation costs could well be significant for explaining movements of paper and specie in, say the 19th century U.S., although

3.1. Net settlement

Although often overlooked, the simplest inside-money scheme is in fact "net settlement," a payment system where, by prior agreement, obligations owed *by* a particular agent are automatically canceled or "set off" using obligations due *from* other participants; remaining obligations must be discharged in some other fashion. By compelling the use of an institution's "due-froms" as inside money, netting in effect allows for mechanical and virtually costless exercise of claims against a counterparty. Kahn et al. (2003) present a model in which netting can effectively reduce the amount of collateral necessary to sustain trade.

Our commodity money example from above can also be used to illustrate the point: Recall that in that example each agent received a unit of commodity money and then waited T periods for it to start generating utility. Thus at any point in time, assets worth TH were not being put to productive use. Also, if $K < T$, it was impossible to use monetary assets to sustain trade beyond what could be achieved with credit.

Now imagine an entity (a "bank") which holds onto $(T-1)H$ in demonetized gold (which we could just as well think of as productive loans) plus H in monetary gold (which it never attempts to demonetize). At any time N agents in the economy have claims on the gold held by the bank. When a supplier becomes a creditor of one of the agents, that agent's credit with the bank is offset against the debt with the supplier. In earlier times, this offset occurred by both agents meeting at the bank and transferring claims on the books of the bank.[27] At any time, both buyer and seller agree on the value of one of these claims: namely $D^{T/N}H$, the value that the holder could receive by accepting monetary gold from the bank and demonetizing it.

It is a small theoretical step from transferring claims on the books of the bank to transferring pieces of paper which represent those claims. These pieces of paper can circulate under exactly the same conditions that gold circulated before. However, by substituting inside money for specie, we have provided a social saving to the economy: someone (in this case, whoever is designated to be the banker) is enjoying the benefits from having a lower level of specie.[28] A natural extension, along the lines of papers noted above, would be to assume that individuals have varying degrees of reliability when holding other peoples' gold, so that not just anybody could become the banker in the story.

Netting is an ancient method of payment that is still widely used today, e.g., in large-value payment systems such as CHIPS and CLS. But netting is also subject to some noteworthy limitations. To be effective, netting arrangements must allow their participants automatically to exercise prior claims against other participants, a power that in some legal settings can conflict with bankruptcy law (Bliss, 2003). Netting is also unlikely to work unless all parties involved are reasonably creditworthy. More reliable agents may have an incentive to exclude riskier agents from netting arrangements, or to force them to undergo screening before they can take part (Kahn and Roberds, 2003).

3.2. Netting and securities settlement

Securities settlement systems also make extensive use of netting arrangements—long and short positions in traded securities are periodically tallied up and replaced with "net positions." The underlying motivation for netting payments and trades in financial claims are the same—to facilitate exchange by economizing on scarce collateral and by ensuring the priority of claims thereto (Baer et al., 2004; Jackson and Manning, 2007). There is also an important practical symbiosis between securities settlement and large-value payment systems. Securities settlement systems depend on large-value payment systems for the final settlement of "funds positions"—positions left over after any netting of securities

the explanation requires the assumption that a store of value form of payment was for some reason mandatory on intermediate links in the credit chain.

[27] In particular, this arrangement mimics the operation of "municipal exchange banks" which were historically prevalent in many European cities (see Kohn, 1999).

[28] Of course in this case, since no one actually goes to redeem the gold in any period, the banker could actually get away with having no specie at all. More complex models would include random needs for small amounts of specie itself and thereby generate a precautionary demand by the bank for specie.

trades has occurred. Conversely, securities settlement systems are an important driver of payments activity over large-value payment systems (Armantier et al., 2008).

Nonetheless, there are some fundamental distinctions between arrangements for netting of securities and netting of payments (Kroszner, 1999). Perhaps the most crucial is transparency: The value of a trade in marketable securities is by its nature more apparent that the value of a payment, which is essentially a (promise to) transfer a relatively opaque debt claim. Securities clearinghouses and their participants can control their exposures with a fair amount of precision by means of devices such as marking positions to market, imposing position limits, and requiring margin calls. Payments netting arrangements, by contrast, depend more critically on their participants' reciprocal trust.

Historically, this distinction has been reflected in the different organization of securities as opposed to payments netting arrangements (Moser, 1998). Payments netting arrangements have traditionally been restricted to "clubs" of banks, whose regulated nature and liquid capital structure help to ensure a sufficient degree of mutual trust. Securities clearing arrangements, by contrast, have traditionally been more inclusive and have not always taken the form of clubs. An open issue is whether securities settlement is best provided by cooperative or profit-maximizing entities, or some specific combination of the two. This debate on the industrial organization of financial settlement systems has been particularly keen in Europe in the wake of monetary unification.[29]

3.3. *Hybrid systems as suppliers of information*

An appealing feature of hybrid arrangements is that they can provide supplemental information on the behavior of individuals over their past trades. Kocherlakota (1998) and related papers have demonstrated that an accumulated pile of money may sometimes be a sufficient statistic for the relevant trading history, but in general it will be desirable to supplement this statistic with additional records. An important function of hybrid (inside-money) payment systems is to provide such information.

Suppose, for example, that trades are only directly observable by the two parties to the trade. Rather than exchange a good for an oral promise, it becomes useful to exchange a good for documentation—evidence that the trade took place. I.O.U.'s and receipts are in fact important parts of payments arrangements: in their own ways they are also stores of value—in this case, evidentiary value. (I.O.U.'s in particular serve as hostages; redeeming them forestalls lawsuits.) Characteristically, I.O.U.'s and receipts are one-sided evidence, in the spirit of Lacker and Weinberg (1989): you can easily hide a receipt, but it is difficult to counterfeit one. Kahn and Roberds (2007) explore a costly enforcement environment in which optimal mechanisms include incentives for collecting evidence and presenting to a court in the case of counterparty malfeasance. In this model, inside money in the form of personally issued transferable debt further extends the parameter space in which efficient transactions can be achieved (see also Mills, 2004). In other words, transferable debt that is tied to an agent's identity (e.g., a check) can provide greater evidence of the course of transactions than would the circulation of an anonymous coin or government-issued paper.

It is worthwhile to point out that the need for evidence has nothing to do with spatial isolation in any meaningful sense—it can arise in highly competitive, multiagent environments. The open-outcry pits on the Chicago futures exchanges have traditionally been regarded as the epitome of competitive markets. Nonetheless, in the midst of all that public haggling, consummation of an individual trade is accomplished by a pair of traders locking eyes and nodding—an act possibly unobserved by anyone else on the trading floor. Thus, even in this centralized situation, identifying evidence in the form of individual traders' trading cards is indispensable.

The role of hybrid arrangements in establishing identity is explored in recent papers by Kahn and Roberds (2008) and Martin et al. (2008). Devices such as credit cards become a way of reducing the cost of establishing identities. To the extent that such identification is imperfect, fraud in the form of identity theft arises as an equilibrium phenomenon. Payment systems only survive if they keep fraud to a manageable level, but it would be prohibitively expensive to eliminate it entirely.

[29] For an introduction to the relevant issues, see e.g., Milne (2007), European Central Bank (2006), Koeppl and Monnet (2006), and Holthausen and Tapking (2007).

4. Payments and monetary policy

The widespread use of RTGS systems for payments between banks implies a close connection between payments and monetary policy. "Policy" interest rates (e.g., the fed funds rate in the U.S.) are, after all, simply the prices at which a central bank is willing to provide funds over an RTGS system today (e.g., Fedwire) in terms of a reverse transfer the following day. As noted in the Introduction, the use of RTGS requires that traditional, "overnight" monetary policy[30] be complemented by some mechanism for the provision of liquidity to the payment system participants. Such a mechanism effectively constitutes an "intraday" monetary policy—a set of conditions under which a central bank is willing to lend funds during its daily operations.[31]

4.1. Overnight vs. intraday rates

In the absence of intraday money markets, intraday liquidity is allocated through various rationing schemes. The details of these schemes differ across countries, but a common theme is generosity. In the U.S., banks were historically given access to free, uncollateralized daylight overdrafts, but now are charged a very low (36 basis point) fee, and only for overdrafts that exceed a cap.[32] Other central banks require collateral for access to intraday credit. Typically, however, they place liberal conditions on that collateral, permitting the use of a wide number of assets and requiring only modest haircuts. Apart from the implicit cost of posting the necessary collateral, there is usually no charge for such intraday credit. In short, the cost intraday liquidity remains close to zero in most countries, irrespective of the value of overnight rates.

A number of papers in the money literature, beginning with Freeman (1996), have sought to explore this dichotomy between overnight and intraday monetary policy.[33] A recurring theme in this group of papers is that intraday monetary policy plays a fundamentally different purpose from overnight monetary policy. In these papers, the demand for overnight funds arises from the private agents' need to smooth consumption and production over time, while the demand for intraday funds arises from the agents' inability to control the timing and magnitude of incoming and outgoing payment demands during the day. Since the requirement to settle via RTGS systems constrains the ability of private agents to contract away these timing mismatches, the implication is that central banks should make intraday credit available on relatively easy terms—at a zero nominal interest rate in the absence of credit risk (Green, 1999).

This conclusion for intraday monetary policy bears an obvious resemblance to well-known Friedman (1969) rule for overnight monetary policy (i.e., a zero nominal interest rate), but there are important differences. At the theoretical level, there seems to be some backing for the idea that, due to unique nature of frictions that can arise in intraday trading, that a zero nominal risk-free intraday rate can enhance welfare, even in environments where a zero-rate overnight policy might be undesirable (Martin, 2004; Millard et al., 2006; Bhattacharya et al., 2007). And while practical central bankers dismiss the Friedman rule as little more than a theoretical curiosity, they seem to have little objection to running intraday policies that are quite close approximations thereto.

While this branch of theoretical literature thus provides some support for existing central-bank intraday monetary policies, the support is subject to some important caveats. Private contracting is sharply constrained in these models, and when agents are allowed access to more sophisticated settlement arrangements (effectively, some form of net settlement) their need for intraday central bank

30 I.e., the usual provision of central bank funds to the banking system through open market operations and discount window loans.

31 This distinction is somewhat artificial: in principle, a central bank could provide liquidity on the same terms at all hours. In practice, however, virtually all central banks sharply distinguish between the two types of policy, and our discussion acknowledges this divergence. See Martin and McAndrews (2007) for a further discussion of this issue and an additional survey of the relevant literature.

32 A substantially higher fee is charged if the intraday overdraft is not repaid by the end of the day.

33 Subsequent papers include Freeman (1999), Zhou (2000), Kahn and Roberds (2001b), Temzelides and Williamson (2001), Williamson (2003), Chapman (2006), Fujiki (2006), Lester et al. (2006), Mills (2006).

credit often either diminishes or vanishes altogether (Green, 1997), with no obvious ill effects. And, as Lacker (2006) points out, in today's world where the "overnight" period of monetary policy spans just a few hours,[34] the distinction between overnight and intraday monetary policy has become less and less relevant. Liquidity now provided via specialized intraday credit facilities could also be provided through other mechanisms—in the U.S. case, Lacker proposes the use of intraday repos combined with payment of interest on excess reserves (mimicking systems already in place in some countries).

4.2. Net vs. gross settlement

A related literature has analyzed intraday monetary policy in a more micro-oriented fashion, and has provided more detailed investigations of strategic interactions in large-value payments environments. The most common theme has been a comparison between net and gross settlement in hypothetical situations where central bank credit is not available. Freixas and Parigi (1998) present a model that incorporates payments between Diamond–Dybvig-type banks. In their setup interbank payment flows may thus stem from either (a) consumption demands of "impatient" consumers or (b) attempts by nervous, privately informed depositors to bail out of insolvent banks. They show that net settlement can economize on liquidity needed for interbank payments, but can be harmful when it results in too low a rate of liquidation for insolvent banks. Hence gross settlement may be preferred on balance. Arrayed against this result are results from numerous models that demonstrate how payment systems operating under RTGS are inherently more susceptible to coordination problems and dominated outcomes—unnecessary delay of payments and, in extremis, "gridlock" as each payment system participant waits for another to make the first payment.[35] Kahn and Roberds (1998) emphasize the liquidity saving of net settlement and find that this may dominate even when the cost of banks' misaligned incentives is taken into account.

Echoing the results of the money literature, the "micro" literature on large-value payment finds that delays and gridlock over RTGS systems can always be ameliorated by sufficiently easy access to central bank credit. Not surprisingly, however, the availability of such central bank "insurance" may introduce a too-big-to-fail problem (Rochet and Tirole, 1996), by diluting banks' incentives to monitor counterparty exposures that can arise in a payments context. Freixas et al. (2000) investigate this tradeoff using an extension of the Freixas and Parigi (1998) approach. They show that central bank liquidity provision over RTGS systems is both costless and desirable when it serves to eliminate gridlock equilibria. It becomes less and less desirable with increasing asymmetry of information about banks' balance sheets, as attempts to stem contagious failures can hinder the prompt revelation of such information.

The inescapability of this tradeoff is even more starkly demonstrated in a recent paper by Fujiki et al. (2008). They consider "payment systems" in the form of optimal mechanisms, in which either insurance or information-revelation considerations may predominate, according to model parameters. In their setup, attempts to mandate an absence of payment disruptions—to remove "systemic risk," as through the requirement to pay via RTGS—may result in a deadweight loss, since it can cause valuable information to be withheld.

Central-bank operators/sponsors of large-value payment systems have traditionally have attempted to resolve this tradeoff by erecting firewalls, i.e., designing relatively "crisis-proof" systems, but restricting access to such systems to regulated banks. Kahn and Roberds (2003) argue that this is a defensible compromise, as it encourages banks to monitor nonbank firms during "normal economic" times, while providing sufficient access to liquidity during crisis periods. In future years these firewalls may come under increasing duress, as financial innovation blurs the distinctions between banks and nonbank firms, and as wholesale systems in different currencies become increasingly bound together through CLS.

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[34] Fedwire closes at 6:30 p.m. New York time and Asian wholesale systems (e.g., BOJ-NET) open just a few hours later, enabling a virtually continuous flow of funds around the globe.

[35] Including Kobayakawa (1997), Angelini (1998, 2000), Bech and Garratt (2003), Kahn et al. (2003), Freeman and Hernandez-Verme (2004).

Lurking in the background is a much more fundamental, but still relatively unexplored question about RTGS: why should banks routinely pay each other in central bank balances, in the first place? The beginnings of an answer may be found in papers such as Holmström and Tirole (1998) and Kocherlakota (2001), which argue that the coercive powers of government allow it to create collateral (government debt and by implication, outside money) in states where adverse shocks might undermine forms of collateral available to the private sector. But what justifies the existence of publicly maintained wholesale systems for trading in this asset?

We have no ready answer to this question. Kahn and Santos (2006) note that participation in public wholesale payment systems necessarily imposes a high degree of interconnectedness between banks, perhaps in excess of what would be efficient under private contracting. Judging from existing payment institutions, developed economies apparently place an extremely high value on the reliability of this "universal interconnectedness." A better understanding of the motivations behind these institutions remains a serious challenge for research in this area.

5. The industrial organization of retail payments

Papers in the monetary literature often assume that payment arrangements are administered by a benevolent social planner, or by a club of payment system participants. Such exercises offer useful benchmarks, particularly for wholesale payments where government-sponsored or cooperative arrangements are the rule. At the retail level, however, payment services, apart from those provided by currency, are usually provided by profit-seeking firms. As purveyors of "information goods" (Varian, 1998), payment service providers are subject to large economies of scale and various types of externalities. These factors have led to significant concentration in the retail payments industry, which in turn has inspired a burgeoning theoretical literature on the industrial organization of payments.[36]

At the center of this literature is a debate about the pricing of payments using credit and debit cards. While there seems to be widespread agreement that electronic forms of payment offer the potential for greater efficiency, card-based payments in particular have in many cases remained more expensive (for merchants) than paper alternatives.[37] The price of card payments is invisible to most purchasers, because contractual agreements (*no-surcharge rules*) between the card providers and merchants prohibit merchants from charging extra for card payments. Instead, the cost of card payments is reflected in *merchant discounts*, fees paid by merchants to the card companies. When the cards are provided through an association such as MasterCard or Visa, an *interchange fee*, paid by the merchant's bank to the purchaser's bank, comprises a significant portion of the merchant discount. Interchange fees are set cooperatively by the card associations. Card providers have also imposed *honor-all-card rules*, requiring merchants to accept all types of cards issued by the provider, if they accept any.

Do the level of prices for card payments and their peculiar structure reflect the exercise of market power by the card providers, or do they simply reflect the nature of the service provided? Rochet and Tirole (2004) argue that the prevalence of the merchant discounts reflects, most fundamentally, a failure of the Coase Theorem to hold in payment situations, leading to what is termed a "two-sided" market for payment services. If for example, as in Rochet and Tirole (2002) the typical retail transaction is between a household and a merchant with some degree of monopoly power, charging consumers for card payments may inefficiently discourage the use of credit, compounding the welfare losses due to monopoly. Charging the other side of the market, i.e., the merchants, for card use (and imposing the no-surcharge rule to make such pricing meaningful) eliminates this problem but may inefficiently subsidize card payments. A similar analysis can be applied to honor-all-cards rule (Rochet and Tirole, 2006b). Beginning with Baxter (1983), the literature has also defended interchange fees as necessary incentives to guarantee participation by all parties (buyer, seller, and their associated payment service providers) to an account-based transaction (for an updated treatment see, e.g., Wright, 2003).

[36] As this literature has been extensively surveyed elsewhere (e.g., Chakravorti, 2003; Hunt, 2003; Rochet and Tirole, 2004; Evans and Schmalensee, 2005; Rochet and Tirole, 2006a), this section provides only a brief outline of some of the relevant topics.

[37] See e.g., Humphrey et al. (2003), Garcia-Swartz et al. (2006a, 2006b).

While this literature has provided numerous theoretical insights, some notable challenges remain. The first is a closer integration of the I/O literature with the monetary literature surveyed above.[38] The second is a need for more consensus building in economists' assessment of current pricing structures in the industry (Evans and Schmalensee, 2005; Rochet and Tirole, 2006a), a process that has been hindered by the lack of available data.

6. Empirical work in payments

The ideal payments dataset would be nothing less than a complete record of all transactions in an economy: a list of all purchases and financial trades, combined with the identities, demographics, and financial conditions of all transactors. Armed with this data, economists could then happily set about investigating and refining the relevance of the theories outlined above.

Obviously no such dataset exists. But there is a huge amount of data "out there." Payments service providers (commercial and central banks, credit card companies, etc.), government agencies, and retailers routinely produce and store immense amounts of payments data, potentially providing some of the richest datasets in economics. But since use of this "primary" type of data poses serious confidentiality issues, to date relatively few researchers have enjoyed access to it. A critical challenge for payments economics is to find some means by which researchers may enjoy access to payments data, without compromising data security and privacy.

In the comparatively small number of cases where researchers have gained access to such data, some meaningful studies have been produced. Most of these have been performed by central bank economists with privileged access to data on wholesale systems. These studies have been informative for theorists, as well as for policy debates about the structure of large-value payment systems, and the nature of their connection to monetary policy (see Section 4 above).

A pioneering study by Humphrey (1986) demonstrated the vulnerability of net settlement systems to the sudden failure of a single participant. Using data on the CHIPS system, Humphrey was able to show that under its then-prevalent settlement rules, the potential for a chain of settlement failures over CHIPS was markedly larger than had previously been supposed. More recent studies by McAndrews and Rajan (2000) and Armantier et al. (2008) use Fedwire data to show that the pattern of payments made over that (RTGS) system accords well with the predictions of models in the theoretical literature—peaking in the late afternoon as participants await payments from other participants. Furfine (2000), also employing Fedwire data, demonstrates a strong statistical link between the Fed's intraday and overnight monetary policies (see also Klee, 2007); Kamhi (2006) provides a similar study for Canada. A number of studies use data on various wholesale systems to investigate the potential for efficiency gains over large-value systems, eliminating "dominated equilibria" through the use of queuing algorithms, selective netting, and related techniques (e.g., Johnson et al., 2004; Galos and Soramäki, 2005). Ashcraft and Duffie (2007) analyze Fedwire data to link fed funds trading to search-theoretic models of exchange, by estimating models that predict the likelihood and price of a "match," or fed funds trade.

To researchers, data from large-value systems are perhaps most interesting when financial markets become, in Bagehot's words, "extremely excited." Two recent studies have offered lessons in this point. Furfine (2006) employs Fedwire data to analyze the market for fed funds during the Long-Term Capital Management episode, finding surprisingly little evidence of disruption to this particular market. McAndrews and Potter (2002) scrutinize activity over Fedwire during and shortly after September 11, 2001, providing evidence that many of the extraordinary liquidity demands experienced during this time stemmed from banks' inability to coordinate payment flows.

Economists studying retail payments have generally not enjoyed access to such high-quality data. Instead, studies of retail payments have most commonly tried to infer consumer payments behavior through general household surveys. Many researchers have focused on the issue of consumers'

[38] See Telyukova and Wright (2008) for a first step in this direction.

choice of payment method, with a particular emphasis on the shift from paper to electronic payment methods.[39]

The most widely employed dataset is the (U.S.) Survey of Consumer Finances (SCF). Studies employing various vintages of the SCF (Kennickell and Kwast, 1997; Stavins, 2001; Klee, 2006a; Mester, 2006) have established that demographic factors such as age, income, and education strongly influence consumers' payment choices, and have documented the shift towards electronic means of payment in recent years (this trend is confirmed in a very extensive payments industry survey reported in Gerdes et al., 2005). Carow and Staten (1999) obtain broadly similar results using data from a survey by Purdue University. Zinman (2006) uses SCF data to infer that debit card use is more common among consumers who are likely to be credit-constrained. Another approach in the literature has been to infer consumer choice from published aggregate data on payment systems and similar data obtained from industry sources. Papers following this approach include Humphrey et al. (2000), Humphrey (2004), Bolt et al. (2005), Garcia-Swartz et al. (2006a, 2006b).

While these analyses have been informative, their lack of transaction-specific data has limited researchers' abilities to model the microeconomic behavior of consumers. This shortcoming has been partially addressed in some recent studies that make use of surveys more specifically targeted at consumers' perceptions of various modes of payment. Hayashi and Klee (2003) use data from a survey by the American Bankers Association to link consumers' use of electronic means of payment with their use of other information technologies. Loix et al. (2005) find similar results using data from Belgian survey. Jonker (2005) analyzes data obtained in a survey in the Netherlands, indicating that consumers there continue to prefer cash for many transactions, despite the perceived convenience of paying by debit card. Recent papers by Borzekowski and Kiser (2006) and Borzekowski et al. (2006) combine the two prevalent approaches in the empirical literature. They are able to estimate demand functions for various methods of payment, using data from the Michigan Survey (demographic data plus consumers' attitudes toward different types of payment) with data on the "average" characteristics of certain payment types (electronic versus paper, time of use, bank fees, etc.).

Only a few empirical studies of retail payments have been able to use actual payments data, some notable examples being Klee (2004, 2006b), Amromin et al. (2007), Fusaro (2006), and Rysman (2007). Using data provided by a grocery retailer, Klee finds that major determinants of consumers' payment choice are time-intensity and transaction size, with time-efficient cash being highly favored for small-value transactions involving just a few items. Analysis of the same dataset indicates a marked transaction-time advantage for debit cards over checks, helping to explain the recent popularity of the former. Amromin et al. (2007) examine the choice of motorists to pay highway tolls by cash or by electronic toll-payment devices, using data provided by a toll authority, and estimate the sensitivity of demand for electronic payment to factors such as price, estimated income, time in making a payment, and other factors that influence convenience of use. Payment choice is shown to be price-elastic for low-income consumers, while convenience factors—largely unaddressed in the theoretical literature—again predominate at higher income levels.

Fusaro (2006) is able to correlate consumers' payment choices to their financial conditions, by using a sample of bank accounts to analyze depositors' preferences for debit over credit card transactions. His analysis suggests that debit cards are often preferred for reasons of ease in recordkeeping—another convenience factor that has not found its way into the theoretical literature. Rysman (2007) analyzes transactions data collected by Visa and is able to show that "network effects" can matter in practice—while consumers may hold multiple payment cards, in practice they tend to concentrate card payments on a single card network, particularly so if local merchants are also prone to accept that card.

In short, empirical payment studies have provided some informative snapshots of payments behavior at the retail and wholesale levels. But there are limits to what information can be gleaned from surveys and aggregate statistics—imagine what financial economics would be like if the only

[39] There are also numerous industry surveys of consumer payment behavior, a partial list of which has been compiled by the Boston Fed (http://www.bos.frb.org/economic/eprg/guide/indrefguide.pdf). A challenge to researchers in this area is how to best make use of these studies, which often rely on proprietary datasets and statistical methodologies.

available data were general surveys of traders and year-end closing prices. Obtaining a more complete understanding of how payment systems actually function will have to await more extensive and more accessible data. And, better empirical work will lead to better theory.

7. Conclusion

Payment is more than a mechanical act. It is, in a sense, the quintessential economic activity, the "glue" that binds together the gains from trade. As such, an act of payment also represents a decision. The choice of whether, when, and how to pay depends on a variety of characteristics of the agents involved in the trade: demographics, value, variability, and liquidity of assets, differential information, risk aversion. The choice also depends on the environment: legal structure enforcing contracts, importance of reputation and ease of damaging it, market interest rates and prices. And in the background, the ability to establish particular terms—indeed the feasibility of trade itself—rests on the availability and cost of a payment system.

In times when payment infrastructure is unchanging, the background becomes transparent: The frequency, the very ordinariness of payment renders it difficult to analyze. We are *not* living in such times. The technological changes of the Internet, the dramatic declines in the costs of computation, and, not least, the institutional changes wrought by international competition and convergence, have led to important changes in the payment systems, both retail and wholesale—and thus made it obvious that payments and system design matter. In such periods renewed interest also arises in the institutional histories and workings of earlier payment regimes.

While the empirical work is still in its infancy, the recent study of payments has also led to interesting theoretical insights and potential policy prescriptions. Even at their most basic, models of payments systems have been useful in public policy deliberations regarding the design and the regulation of clearing and settlement systems domestically and internationally. The most recent round of payments models have also begun to provide adequate microfoundations for understanding the costs and benefits of alternative payments system arrangements. Our examination of this theoretical work leads to the following messages:

1. Despite our habit of modeling money in geographically-dispersed frameworks, payments still matter even if the world is not decentralized. As long as a time mismatch in trade arises and enforcement of credit arrangements is imperfect, payment systems design will affect an economy.
2. Informational limitations are a key factor in limiting enforcement, and thus are a key factor in the success of a payment system. Verification of identity is central to accounts systems, just as counterfeit protection is central to store-of-value systems.
3. Informational limitations are not set in stone. At a cost, they can be and are overcome. Although anonymity places severe limitations on payment arrangements, anonymity can be pierced at a cost. If the benefit is high enough the institutions for gathering or recording the information develop.

With microfoundations in place, payments models are now able to handle a significantly larger set of issues. On the horizon are linkups with the law and economics literature, reappraising our understanding of contracts and payments law (for example, issues surrounding identity theft and transactions privacy) in terms of the new insights. Also on the horizon are better models of the interface between large-value payment systems and the conduct of monetary policy. Ultimately these should contribute to a better microfoundation of the monetary transmission mechanism than is provided by, say, a simple cash-in-advance constraint.

Our models have made a start—but the models have just scratched the surface. Plumbers (and plumbing inspectors) will not be out of a job any time soon.

References

Aiyagari, S.R., Wallace, N., 1997. Government transaction policy, the medium of exchange, and welfare. J. Econ. Theory 74, 1–18.
Aiyagari, S.R., Williamson, S.D., 2000. Money and dynamic credit arrangements with private information. J. Econ. Theory 91, 248–279.

Almeida, H., Campello, M., Weisbach, M.S., 2004. J. Finance 59 (4), 1777–1804.

Amromin, G., Jankowski, C., Porter, R.D., 2007. Transforming payment choices by doubling fees on the Illinois tollway. Fed. Reserve Bank Chicago Econ. Perspect. 31 (2), 22–47.

Andolfatto, D., Nosal, E., 2003. A theory of money and banking. Working Paper, Fed. Reserve Bank Cleveland.

Angelini, P., 1998. An analysis of competitive externalities in gross settlement systems. J. Banking Finance 22, 1–18.

Angelini, P., 2000. Are banks risk averse? Intraday timing of operations in the interbank market. J. Money, Credit, Banking 32, 54–73.

Araujo, L., 2004. Social norms and money. J. Monet. Econ. 51, 241–256.

Armantier, O., Arnold, J.B., McAndrews, J.J., 2008. Changes in the timing distribution of Fedwire funds transfers. Fed. Res. Bank New York Econ. Pol. Rev. 14 (2), 83–112.

Ashcraft, A.B., Duffie, D., 2007. Systemic illiquidity in the federal funds market. Amer. Econ. Rev. 97 (2), 221–225.

Baer, H., France, V.G., Moser, J.T., 2004. Opportunity cost and prudentiality: An analysis of collateral decisions in bilateral and multilateral settings. Res. Finance 21, 201–227.

Bank of England, 2002. Access to settlement accounts. Accessed online at http://www.bankofengland.co.uk/financialstability/paymentsettlementsystems/pdf/boesettleaccs021128.pdf.

Baxter, W.F., 1983. Bank exchange of transactional paper: Legal and economic perspectives. J. Law Econ. 26, 541–588.

Bech, M.L., Garratt, R., 2003. The intraday liquidity management game. J. Econ. Theory 109, 198–219.

Berentsen, A., Camera, G., Waller, C., 2007. Money, credit and banking. J. Econ. Theory 135 (1), 171–195.

Bhattacharya, J., Haslag, J.H., Martin, A., 2007. Why are overnight rates higher than intraday rates? Mimeo, Fed. Reserve Bank New York.

Bliss, R., 2003. Bankruptcy law and large complex financial organizations: A primer. Fed. Reserve Bank Chicago Econ. Perspect. 27 (1), 48–58.

Bolt, W., Humphrey, D., Uittenbogaard, R., 2005. The effect of transaction pricing on the adoption of electronic payments: A cross-country comparison. Working paper, Fed. Reserve Bank Philadelphia.

Borzekowski, R., Kiser, E.K., 2006. The choice at the checkout: Quantifying demand across payment instruments. Finance and Economics Discussion Paper, Board of Governors of the Fed. Reserve System.

Borzekowski, R., Kiser, E.K., Ahmed, S., 2006. Consumers' use of debit cards: Patterns, preferences and price response. Finance and Economics Discussion Paper, Board of Governors of the Fed. Reserve System.

Bullard, J.D., Smith, B.D., 2003. Intermediaries and payments instruments. J. Econ. Theory 109, 172–197.

Camera, G., 2001. Dirty money. J. Monet. Econ. 47 (2), 377–415.

Carow, K.A., Staten, M.E., 1999. Debit, credit, and cash: Survey evidence on gasoline purchases. J. Econ. Bus. 51, 409–422.

Cavalcanti, R., Wallace, N., 1999. A model of private banknote issue. Rev. Econ. Dynam. 2, 104–136.

Chakravorti, S., 2003. Theory of credit card networks: A survey of the literature. Rev. Network Econ. 2, 50–68.

Chapman, J.T.E., 2006. Policy in international payment systems with a timing friction. Paper presented at the Economics of Payments II, Federal Reserve Bank of Atlanta, March.

Committee on Payment and Settlement Systems, 1990. Report of the Committee on Interbank Netting Schemes of the Central Banks of the Group of Ten Countries. Bank for International Settlements, Basel.

Committee on Payment and Settlement Systems, 1996. Settlement Risk in Foreign Exchange Transactions, Bank for International Settlements, Basel.

Committee on Payment and Settlement Systems, 2007. Statistics on Payment and Settlement Systems in Selected Countries—Figures for 2005. Bank for International Settlements, Basel.

Corbae, D., Ritter, J., 2004. Decentralized credit and monetary exchange without public record keeping. Econ. Theory 24, 933–951.

Corbae, D., Temzelides, T., Wright, R., 2003. Directed matching and monetary exchange. Econometrica 71, 731–756.

Diamond, P., 1990. Pairwise credit in search equilibrium. Quart. J. Econ. 105, 285–319.

Diamond, D., Dybvig, P., 1983. Bank runs, deposit insurance, and liquidity. J. Polit. Economy 91, 401–419.

European Central Bank, 2006. Issues Related to Central Counterparty Clearing, Joint Conference, Frankfurt am Main, 03–04 April 2006. Proceedings available at http://www.ecb.int/events/conferences/html/ccp.en.html.

Evans, D.S., Schmalensee, R., 1999. Paying with Plastic: The Digital Revolution in Buying and Borrowing. MIT Press, Cambridge, MA.

Evans, D.S., Schmalensee, R., 2005. The economics of interchange fees and their regulation: An overview. Paper delivered at Interchange Fees in Credit and Debit Card Industries: What role for Public Authorities? Federal Reserve Bank of Kansas City, May.

Fratianni, M., Spinelli, F., 2006. Did Genoa and Venice kick a financial revolution in the quattrocento? Working Paper, Oesterreichische Nationalbank.

Freeman, S., 1996. The payments system, liquidity, and rediscounting. Amer. Econ. Rev. 86, 1126–1138.

Freeman, S., 1999. Rediscounting under aggregate risk. J. Monet. Econ. 43, 197–216.

Freeman, S., Hernandez-Verme, P., 2004. Default and fragility in the payments system. Paper presented at the Economics of Payments, Federal Reserve Bank of Atlanta, March.

Freixas, X., Parigi, B.M., 1998. Contagion and efficiency in gross and net interbank payment systems. J. Finan. Intermediation 7, 3–31.

Freixas, X., Parigi, B.M., Rochet, J.C., 2000. Systemic risk, interbank relations, and liquidity provision by the central bank. J. Money, Credit, Banking 32, 611–638.

Friedman, M., 1969. The Optimum Quantity of Money. The Optimum Quantity of Money and Other Essays. Aldine, Chicago.

Fujiki, H., 2006. Institutions of foreign exchange settlement in a two-country model. J. Money, Credit, Banking 38, 697–719.

Fujiki, H., Green, E.J., Yamazaki, A., 2008. Incentive efficient risk sharing in a settlement mechanism. J. Econ. Theory 142 (1), 178–195.
Furfine, C.H., 2000. Interbank payments and the daily federal funds rate. J. Monet. Econ. 46, 535–553.
Furfine, C.H., 2006. The costs and benefits of moral suasion: Evidence from the rescue of long-term capital management. J. Bus. 79, 593–622.
Fusaro, M.A., 2006. Debit vs. credit: A rational model of self-control with evidence from checking accounts. Mimeo, East Carolina University.
Galos, P., Soramäki, K., 2005. Systemic risk in alternative payment system designs. Working Paper, European Central Bank.
Garcia-Swartz, D.D., Hahn, R.W., Layne-Farrar, A., 2006a. The move toward a cashless society: A closer look at payment instrument economics. Rev. Network Econ. 5, 175–198.
Garcia-Swartz, D.D., Hahn, R.W., Layne-Farrar, A., 2006b. The move toward a cashless society: Calculating the costs and the benefits. Rev. Network Econ. 5, 199–228.
Gerdes, G., Walton, J.K., Liu, M.X., Parke, D.W., 2005. Trends in the use of payment instruments in the United States. Fed. Reserve Bull. 91, 180–201.
Green, E.J., 1997. Money and debt in the structure of payments. Bank Japan Monet. Econ. Stud. 15, 63–87.
Green, E.J., 1999. Panel: Thoughts on the future of payments and central banking: We need to think straight about electronic payments. J. Money, Credit, Banking 31, 668–670.
Green, E.J., 2004. Challenges for research in payments. In: Invited Lecture at the Economics of Payments Federal Reserve Bank of Atlanta, March.
Green, E.J., Todd, R.M., 2001. Some thoughts on the Fed's role in the payments system. Fed. Reserve Bank Minneapolis Quart. Rev. 25 (1), 12–27.
Hayashi, F., Klee, E., 2003. Technology adoption and consumer payments: Evidence from consumer data. Rev. Network Econ. 2 (2), 175–190.
He, P., Huang, L., Wright, R., 2005. Money and banking in search equilibrium. Int. Econ. Rev. 46 (2), 637–670.
Holmström, B., Tirole, J., 1998. Public and private supply of liquidity. J. Polit. Economy 106, 1–40.
Holthausen, C., Tapking, J., 2007. Raising rival's cost in the securities settlement industry. J. Fin. Intermediation 16, 91–116.
Humphrey, D.B., 1986. Payment finality and the risk of a settlement failure. In: Saunders, A., White, L.J. (Eds.), Technology and the Regulation of Financial Markets: Securities, Futures, and Banking. Heath, Lexington, MA, pp. 97–120.
Humphrey, D.B., 2004. Replacement of cash by cards in U.S. consumer payments. J. Econ. Bus. 56, 211–225.
Humphrey, D.B., Pulley, L.B., Vesala, J.M., 2000. The check's in the mail: Why the United States lags in the adoption of cost-saving electronic payments. J. Fin. Services Res. 17, 17–39.
Humphrey, D.B., Willesson, M., Lindblom, T., Bergendahl, G., 2003. What does it cost to make a payment? Rev. Network Econ. 2, 159–174.
Hunt, R.M., 2003. An introduction to the economics of payment card networks. Rev. Network Econ. 2, 80–96.
Intraday Liquidity Management Task Force, 2000. Intraday liquidity management in the evolving payment system: A study of the impact of the Euro, CLS bank, and CHIPS finality. Payments Risk Committee, New York.
Jackson, J.P., Manning, M.J., 2007. Comparing the pre-settlement risk implications of alternative clearing arrangements. Working paper, Bank of England.
Jin, Y., Temzelides, T., 2004. On the local interaction of money and credit. Rev. Econ. Dynam. 7, 143–156.
Johnson, K., McAndrews, J.J., Soramäki, K., 2004. Economizing on liquidity with deferred settlement mechanisms. Fed. Reserve Bank New York Econ. Pol. Rev. 10 (3), 51–72.
Jonker, N., 2005. Payment instruments as perceived by consumers—A public survey. Working paper, De Nederlandsche Bank.
Judson, R., Porter, R., 2003. Estimating the worldwide volume of U.S. counterfeit currency: Data and extrapolation. Finance and Economics Discussion Paper, Board of Governors of the Federal Reserve System.
Kahn, C.M., 2006. Payment cards—Economy wide benefits: The pattern of developments in payments provision. Working paper, The University of Illinois.
Kahn, C.M., Roberds, W., 1998. Payment system settlement and bank incentives. Rev. Fin. Stud. 11, 845–870.
Kahn, C.M., Roberds, W., 2001a. The CLS bank: A solution to the problem of international payments settlement? Carnegie-Rochester Conf. Ser. Public Pol. 54, 191–226.
Kahn, C.M., Roberds, W., 2001b. Real-time gross settlement and the costs of immediacy. J. Monet. Econ. 47, 299–319.
Kahn, C.M., Roberds, W., 2003. Payments settlement under limited enforcement: Public versus private systems. Working paper, Federal Reserve Bank of Atlanta.
Kahn, C.M., Roberds, W., 2007. Transferability, finality, and debt settlement. J. Monet. Econ. 54, 955–978.
Kahn, C.M., Roberds, W., 2008. Credit and identity theft. J. Monet. Econ. 55 (2), 251–264.
Kahn, C.M., Santos, J.A.C., 2006. Endogenous financial fragility and prudential regulation. Mimeo, Federal Reserve Bank of New York.
Kahn, C.M., McAndrews, J.J., Roberds, W., 2003. Settlement risk under net and gross settlement. J. Money, Credit, Banking 47, 299–319.
Kamhi, N., 2006. LVTS, the overnight market, and monetary policy. Working paper, Bank of Canada.
Kashyap, A., Rajan, R., Stein, J., 2002. Banks as liquidity providers: An explanation of the co-existence of lending and deposit-taking. J. Finance 57, 33–73.
Kennickell, A.B., Kwast, M., 1997. Who uses electronic banking? Finance and Economics Discussion Paper, Board of Governors of the Federal Reserve System.
Kim, C.S., Mauer, D.C., Sherman, A.E., 1998. The determinants of corporate liquidity: Theory and evidence. J. Finan. Quant. Anal. 33 (3), 305–334.
Kiyotaki, N., Moore, J., 1997. Credit chains. Mimeo, London School of Economics.

Kiyotaki, N., Moore, J., 2000. Inside money and liquidity. Mimeo, London School of Economics.
Kiyotaki, N., Wright, R., 1989. On money as a medium of exchange. J. Polit. Economy 97, 927–954.
Klee, E., 2004. How people pay? Evidence from grocery store data. Mimeo, Board of Governors of the Fed. Reserve System.
Klee, E., 2006a. Families' use of payment instruments during a decade of change in the U.S. payment system. Finance and Economics Discussion Paper, Board of Governors of the Fed. Reserve System.
Klee, E., 2006b. Paper or plastic? The effect of time on check and debit card use at grocery stores. Finance and Economics Discussion Paper, Board of Governors of the Fed. Reserve System.
Klee, E., 2007. Operational problems and aggregate uncertainty in the federal funds market. Finance and Economics Discussion Paper, Board of Governors of the Fed. Reserve System.
Kobayakawa, S., 1997. The comparative analysis of settlement systems. Centre for Economic Policy Research Discussion Paper.
Kocherlakota, N.R., 1998. Money is memory. J. Econ. Theory 81, 232–251.
Kocherlakota, N.R., 2001. Risky collateral and deposit insurance. Adv. Macroeconom. 1 (1). Article 2.
Kocherlakota, N.R., Wallace, N., 1998. Incomplete record-keeping and optimal payment arrangements. J. Econ. Theory 81, 272–289.
Koeppl, T.V., Monnet, C., 2006. Central counterparties. Paper presented at Joint Conference of the ECB and the FRBC on the role of Central Counterparties, European Central Bank, April.
Kohn, M., 1999. Early deposit banking. Working paper, Dartmouth University.
Kroszner, R.S., 1999. Can the financial markets privately regulate risk? The development of derivatives clearinghouses and recent over-the-counter innovations. J. Money, Credit, Banking 31, 599–618.
Kuttner, K.N., McAndrews, J.J., 2001. Personal on-line payments. Fed. Reserve Bank New York Econ. Pol. Rev. 7 (3), 35–50.
Lacker, J.M., 2006. Central bank credit in the theory of money and payments. In: Invited Lecture at the Economics of Payments II. Federal Reserve Bank of New York, March.
Lacker, J.M., Weinberg, J.A., 1989. Optimal contracts under costly state falsification. J. Polit. Economy 97, 1345–1363.
Lagos, R., Wright, R., 2005. A unified framework for monetary theory and policy analysis. J. Polit. Economy 113, 463–484.
Lester, B., Millard, S., Willison, M., 2006. Optimal settlement rules for payment systems. Paper presented at the Economics of Payments, Federal Reserve Bank of New York, March.
Li, Y., 2001. A search model of money and private debt with applications to monetary policy. Int. Econ. Rev. 42, 925–946.
Loix, E., Pepermans, R., Van Hove, L., 2005. Who's afraid of the cashless society? Belgian survey evidence. Paper presented at Consumer Behavior and Payment Choice, Fed. Reserve Bank Boston, October.
Lowe, P., 2005. Payments system reform: The Australian experience. Paper delivered at Interchange Fees in Credit and Debit Card Industries: What Role for Public Authorities? Fed. Reserve Bank Kansas City, May.
Martin, A., 2004. Optimal pricing of intraday liquidity. J. Monet. Econ. 51, 401–424.
Martin, A., McAndrews, J.J., 2007. Why are there no intraday money markets? Mimeo, Fed. Reserve Bank New York.
Martin, A., Orlando, M., Skeie, D., 2008. Payment networks in a search model of money. Rev. Econ. Dynam. 11 (1), 104–132.
McAndrews, J.J., Potter, S.M., 2002. Liquidity effects of the events of September 11, 2001. Fed. Reserve Bank New York Econ. Pol. Rev. 8 (2), 59–79.
McAndrews, J.J., Rajan, S., 2000. The timing and funding of Fedwire funds transfers. Fed. Reserve Bank New York Econ. Pol. Rev. 6 (2), 17–32.
McAndrews, J.J., Trundle, J., 2001. New payment system design: Causes and consequences. Bank Engl. Fin. Stability Rev. 11, 127–136.
Mester, L.J., 2006. Changes in the use of electronic means of payment: 1995–2004. Fed. Reserve Bank Philadelphia Bus. Rev. 0 (2), 26–30.
Millard, S., Speight, G., Willison, M., 2006. Why do central banks observe a distinction between intraday and overnight rates? Mimeo, Bank of England.
Milne, A.K.L., 2007. The industrial organization of post-trade settlement. J. Banking Finance 31 (10), 2945–2961.
Mills, D.C., 2004. Mechanism design and the role of enforcement in Freeman's model of payments. Rev. Econ. Dynam. 7, 219–236.
Mills, D.C., 2006. Alternative central bank policies for liquidity provision in a model of payments. J. Monet. Econ. 53 (7), 1593–1611.
Moser, J.T., 1998. Contracting innovations and the evolution of clearing and settlement methods at futures exchanges. Working paper, Federal Reserve Bank of Chicago.
Nosal, E., Rocheteau, G., 2006. The economics of payments. Policy discussion paper, Federal Reserve Bank of Cleveland.
Opler, T., Pinkowitz, L., Stulz, R.H., Williamson, R., 1999. The determinants and implications of corporate cash holdings. J. Finan. Econ. 52 (1), 3–46.
Ostroy, J.M., Starr, R.M., 1974. Money and the decentralization of exchange. Econometrica 42, 1093–1113.
Quinn, S., Roberds, W., 2006. An economic explanation of the early Bank of Amsterdam, debasement, bills of exchange and the emergence of the first central bank. Working paper, Fed. Reserve Bank Atlanta.
Rochet, J.-C., Tirole, J., 1996. Interbank lending and systemic risk. J. Money, Credit, Banking 28, 733–762.
Rochet, J.-C., Tirole, J., 2002. Some economics of payment card associations. RAND J. Econ. 33, 549–570.
Rochet, J.-C., Tirole, J., 2004. Two-sided markets: An overview. IDEI working paper, University of Toulouse.
Rochet, J.-C., Tirole, J., 2006a. Externalities and regulation in card payment systems. Rev. Network Econ. 5, 1–14.
Rochet, J.-C., Tirole, J., 2006b. Tying in two-sided markets and the honor all cards rule. Mimeo, IDEI, University of Toulouse.
Rysman, M., 2007. An empirical model of payment card usage. J. Ind. Econ. 55 (1), 1–36.
Samuelson, P.A., 1958. An exact consumption-loan model of interest with or without the contrivance of money. J. Polit. Economy 66, 467–482.
Shi, S., 1996. Credit and money in a search model with divisible commodities. Rev. Econ. Stud. 63, 627–652.

Speight, G., Norman, B., Shaw, R., 2006. The evolution of payment arrangements and central banks. Mimeo, Bank of England.
Stavins, J., 2001. Effect of consumer characteristics on payment instruments. Fed. Reserve Bank Boston New England Econ. Rev. (3), 19–31.
Starr, R.M., 1974. The price of money in a pure exchange monetary economy with taxation. Econometrica 42 (1), 45–54.
Taub, B., 1994. Currency and credit are equivalent mechanisms. Int. Econ. Rev. 35, 921–956.
Telyukova, I.A., Wright, R., 2008. A model of money and credit, with application to the credit card puzzle. Rev. Econ. Stud. 75 (2), 629–647.
Temzelides, T., Williamson, S.D., 2001. Payments system design in deterministic and private information environments. J. Econ. Theory 99, 297–326.
Temzelides, T., Yu, J., 2004. Lack-of-recall and centralized monetary trade. Int. Econ. Rev. 45, 1221–1227.
Townsend, R.M., 1980. Models of money with spatially separated agents. In: Karaken, J.H., Wallace, N. (Eds.), Models of Monetary Economies. Federal Reserve Bank of Minneapolis Press, Minneapolis, pp. 265–303.
Townsend, R.M., 1987. Economic organization with limited communication. Amer. Econ. Rev. 77, 954–971.
Varian, H.R., 1998. Markets for information goods. Mimeo.
Velde, F., Weber, W., 2000. A model of bimetallism. J. Polit. Economy 108 (6), 1210–1234.
Williamson, O.E., 1985. The Economic Institutions of Capitalism. The Free Press, New York, p. 177.
Williamson, S.D., 1999. Private money. J. Money, Credit, Banking 31, 469–491.
Williamson, S.D., 2003. Payments systems and monetary policy. J. Monet. Econ. 50, 475–495.
Willison, M., 2005. Real-time gross settlement and hybrid payment systems: A comparison. Working paper, Bank of England.
Wright, J., 2003. Optimal card payment systems. Europ. Econ. Rev. 47, 587–612.
Wright, R., 2008. Search-and-matching models of monetary exchange. In: Durlauf, S.N., Blume, L.E. (Eds.), The New Palgrave Dictionary of Economics, second ed. Palgrave MacMillan.
Zinman, J., 2006. Debit or credit? Mimeo, Dartmouth College.
Zhou, R., 2000. Understanding intraday credit in large-value payment. Fed. Reserve Bank Chicago Econ. Perspect. 24 (3), 29–44.