

Central banking and the economics of information

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Introduction and summary

Advances in the economic management of information have worked pervasive change throughout the world economy and its financial system. Change due to the adoption of electronic computing and communications has been highly visible. Another kind of advance, in the design of organizations (including financial institutions) to allow them to function well in private-information environments, has been equally significant. In this article, I examine how both types of advance affect a key sector of the financial system: central banking. This examination focuses on the following three areas.

First, I study the implications of innovation induced by information technology in payment arrangements for monetary policy objectives. Some observers have suggested that such innovations, including the introduction of electronic money products or *e-money*, may nullify the relationship between issuance of money by the central bank and the price level.¹ I explain why I think that this will not happen. More precisely, I explain why innovative payment arrangements will not nullify the long-run identity between the rate of money growth and the rate of increase of the price level.

Second, I consider operational and design requirements for electronic information systems to ensure the integrity and security of the financial system (including central bank settlement of large-value payments). I conclude that an enlarged role for central banks may be warranted. Specifically, to a considerably greater extent than in the past, central bankers need to understand themselves as customers and advocates in a market for information technology, where the quality of goods and services provided by the market, rather than only the individual choices of the central bank itself, determines how high a level of integrity and security is feasible.

Third, I examine the meaning of, and requirements for, transparency of central bank decision-making.

A central bank is usually said to be transparent if it makes its decisions visible to the public. For example, the Federal Reserve increased its transparency in the 1990s when it began to announce the new target for the federal funds rate immediately after the Federal Open Market Committee (FOMC) meeting in which the target was set. I suggest extending the concept of transparency beyond decisions per se to the full range of information about the central bank that is relevant to the formulation and implementation of present and future monetary policy. I argue that the decentralized structure that establishes 12 Reserve Banks as independent corporations enhances the transparency of the Federal Reserve System.

Information technology, the payments system, and monetary policy

Payments innovation as a central banking issue

Information technology is engendering rapid innovation in payment systems. E-money designed for small-value payments is the family of innovations within the past decade that is most visible to the broad public.² In addition, there are new technology applications that promise dramatic expansion of the applicability of netting and related procedures for large-value payments. The most conspicuous (albeit not yet operational) worldwide example is the continuous linked settlement (CLS) system, which was designed in response to market and supervisory pressure to reduce the current lag of several days between the initiation

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of a foreign exchange transaction and its completion.³ In the U.S., the Clearing House Interbank Payments System (CHIPS) has incorporated a sophisticated trade-matching algorithm in its payments system for making large-value dollar funds transfers. The new protocol makes CHIPS settlement a closer substitute for Fedwire, the Federal Reserve's real-time gross settlement system, as a way to transfer funds for most purposes.⁴

Retail e-money is more similar to these large-value payment innovations than may be apparent. As typically conceived, an electronic-money product resembles a check in being transferable prior to settlement, although in detail, the e-money is a virtual bearer security while the check is a negotiable instrument.⁵ An electronic-money product resembles a credit card in giving the payee a claim on the issuer rather than on the payor or drawer. What is new about e-money, at least relative to recent payment arrangements, is the combination of these two features. While the negotiability of a check is seldom used in practice because each drawer's ability to settle is not widely established, e-money is envisioned to be routinely transferred because the issuer's ability to settle will be public knowledge. The familiar payment instrument (although no longer used in most countries) that e-money will most closely resemble, then, is a banknote.⁶ Banks used to accept outside money (typically gold or silver coin, in the old days) as payment for a paper certificate, the banknote, that the bank would exchange for outside money on demand. Someone who accepted a banknote could pay it to someone else who would redeem it, and the payor and payee would thus avoid the risk and inconvenience of using outside money directly for their transaction.

One way of looking at the common use of an instrument's transferability is as a netting arrangement. The issuer or intermediary accepts a payment from the first payor and makes a payment to the last payee to use the instrument, with an arbitrary number of intervening transactions being settled without the issuer's direct involvement, but simply by transfer of the instrument. Moreover, the profitability of e-money, which derives from the issuer being able to convert money received in payment to an illiquid security with positive yield until having to make payment, relies on this netting to forestall premature liquidation of the security. From this perspective, e-money shares the same main feature of economic interest of the large-value payment innovations currently being developed.

With that preamble, I propose that increased scope for net settlement is the predominant aspect of payments system innovation that might raise a

fundamental issue of monetary policy.⁷ (This is not to say that it would be the only aspect relevant for other purposes, such as addressing prudential, competitive, and consumer-protection issues.) By a fundamental issue, I mean one that current understanding would not provide a good way to address. Extensive conversion of reservable deposits, or of deposits included in a monetary aggregate, to e-money might be a serious problem for monetary policy in some sense, for example, but it would not be a fundamental problem, because reformulation of the basis for computing the reserve requirement or monetary aggregate to include e-money would be an obvious solution. By this premise, a potentially open-ended examination of the implications of innovation for monetary policy can be narrowed to an examination of the monetary implications of increasing the scope of net settlement.

Several years ago, central bankers concluded that the implications of payments system innovation for the formulation and implementation of monetary policy in the context of e-money were not fundamental.⁸ This conclusion was based partly on the argument that the use of money for small-value transactions is insignificant for monetary policy. That argument, of course, provides no assurance regarding innovation in large-value payments. However, there were other, independent arguments that reached the same conclusion. The central bankers suggested that, in general, as long as there is a way to induce demand for reserves, and as long as the central bank can finance open-market operations to affect the supply of reserves, conduct of monetary policy broadly along present lines should remain feasible. Inducing demand might require some regulatory distortion if interest were not to be paid on the reserves, and providing resources for open-market operations might require funding of the central bank with tax revenue (as is already done in the UK) if interest were to be paid, but even such measures were not generally viewed as serious obstacles to the conduct of monetary policy.

The question that past discussion has not resolved or even framed very explicitly is whether innovation in payment arrangements might conceivably cause the *objective* of monetary policy to change. Central bankers view themselves as making a tradeoff between the avoidance (or control) of inflation and other policy objectives such as growth and full employment. If innovation in payment arrangements were to reduce the sensitivity of the economy to inflation, then central bankers presumably should respond by giving greater weight to those other policy objectives relative to the inflation objective.

Two models of payments innovation and inflation

I discuss two economic models that purport to address the effect of payment innovation on the welfare cost of inflation. The first model suggests that innovation should reduce the welfare cost of a given level of inflation. However, the model incorporates an assumption inappropriate to studying this question. I formulate an alternative model that suggests that the welfare cost of inflation is unaffected by innovation.

I start off with a well-known model, according to which payment innovation potentially can reduce the sensitivity of the economy to inflation.⁹ This model posits that transactions can be made by using either money or an alternative, nonmonetary, technology. The researchers who developed the model call the alternative technology *credit*, *financial intermediation*, or *e-money*. A buyer's decision which technology to use is based on cost minimization. The cost of using money is the interest income that is forgone by holding money rather than an interest-bearing, but illiquid, security.¹⁰ The buyer's cost of using the alternative technology—call it *credit*—for a particular transaction depends on the seller. For any buyer, there are a few sellers—think of them as being his immediate neighbors—to whom it is very inexpensive to establish creditworthiness, a few others to whom it is very costly, and other sellers at every level in between. Each buyer desires the differentiated goods of all sellers, so he will use credit to buy from his neighbors but money to buy from distant strangers. There will be some critical distance at which buyers switch from using money to credit.

Now suppose that, for every distance, the cost of establishing creditworthiness to a seller at that distance falls by half. Then, if the seignorage tax does not change, the critical distance will double. Some payments that would have been made with money before will now be made with credit—in particular, those payments from buyers to sellers who are located farther away than the old critical distance but closer than the new one. Such a fall in the cost of establishing creditworthiness is how a payment innovation is represented in this model.

The utility loss due to a marginal increase in the price of a good is proportional to the quantity of the good consumed.¹¹ More generally, the utility loss due to a uniform marginal increase in the prices of a set of goods is proportional to the sum of the quantities of those goods consumed. An increase in the rate of inflation (that is, in the seignorage tax rate) translates into an after-tax price increase on all goods bought with money. The upshot is that the fewer are the goods that a buyer buys with money, the smaller is

the buyer's utility loss from an increase in the rate of inflation. Since innovation in payment arrangements reduces the set of goods that each buyer buys with money, innovation reduces the aggregate welfare cost of inflation according to this analysis. An implication would seem to be that, as innovation decreases the cost of alternative payments technology and correspondingly increases its use, central bankers should care less about inflation and should turn their attention more to other policy goals.

The most satisfactory way of modeling an innovation in payment arrangements is to represent it in a general equilibrium model having the feature that people's willingness to accept money in exchange for valuable commodities arises naturally as an equilibrium phenomenon, rather than being imposed by an ad hoc constraint against goods-for-goods trades not involving money.¹² The foregoing analysis is best regarded as an essay to think in rough and ready terms about how such a fully articulated model would work. The analysis leans heavily on the premise that money is not used at all in making credit payments. In contrast, actual credit is almost always nominal, so money is essential to extinguish or settle it. Since the payment innovations that are being made on the basis of information technology are specifically means of economizing on the use of money for settlement, the purpose itself must be important for understanding the innovations. The observation that there is no debt-settlement role for money in the model just presented should be a warning bell about its appropriateness for this use.

A more appropriate proxy for a fully articulated analysis, I think, is to imagine a payment arrangement as being a protocol according to which a buyer can costlessly issue real debt (that is, make enforceable promises to provide specified quantities of goods at future dates) to finance part of a purchase, but according to which at least a specified fraction of the value of the purchase must be paid in money. This fraction corresponds to the "netting ratio," that is, to the ratio of the aggregate value of gross payments settled via the arrangement to the aggregate value of net payments made in money to effect settlement. Thus an increase in the netting ratio of the economy is a good representation of a payments innovation. Now, as a rough and ready analogy, think of the netting ratio as being just the traditional money multiplier with net payment playing the role of inside money. The clear intuition from this analogy ought to be that a payments innovation will raise the price level (by increasing the amount of inside money) but have no other effect. This intuition follows from the idea that

money is neutral in the long run, that is, that an increase in the stock of money may have transitory effects on real economic activity but will have no effect asymptotically. In particular, the long-run welfare effects of monetary policy should be identical in the post-innovation economy to what they were in the pre-innovation economy. This is the conclusion that I would expect a sound, fully articulated analysis to yield. On the basis of this expectation, I do not believe that innovation in payment arrangements constitutes a fundamental change.

Requirements for integrity and security of the financial system

Central banks have undertaken to promote the integrity and security of the financial system infrastructure, and a central bank is directly accountable for the integrity and security of its own operations.¹³ Integrity means immunity from failure when operated and used even under extreme conditions (such as during a period of financial market volatility) but in good faith. Security means immunity from failure due to attempted impairment or bad-faith use by an authorized or unauthorized user.

Major components of financial system infrastructure have relied on electronic computing and communication technology for several decades. In most countries these components include, for example, the real-time gross settlement system for large-value transfers and the system of ownership registration for government securities. Other components, such as securities-market trading systems and systems for assessing and documenting the credit quality of assets intended for securitization are progressively becoming dominated by electronic technology as well.

Old-fashioned requirements of security and integrity continue to be relevant in the context of electronic information technology. For example, physical facilities have to be guarded adequately; the authorization, execution, and recording of transactions ought not to be done by the same person; and there must be sufficient investment in maintenance and redundancy of equipment to control the risk of mechanical and electrical failures.

In addition, three features of electronic technology, and of software in particular, create problems that are new or much more intense than before. First, a software defect is present in exactly the same form on all machines that run the software, so that redundancy of equipment provides no protection from such a defect. Second, there is the problem that software tends to be subject to dramatic failure on account of a defect in any one of a profusion of details. For example, in

1985, when the number of distinct issues of U.S. government securities grew too large to be represented by the address field in a program instruction (analogous to the recent century-date-change problem, in which the commonly used two-digit representation of a year ceased to be adequate), the unintended behavior of the program had business consequences that required the Bank of New York to borrow more than \$20 billion at the discount window of the Federal Reserve Bank of New York.¹⁴ More important, this episode highlighted the potential for serious disruptions to the payments system and the financial markets, although they were avoided in this instance.¹⁵ Third, besides the problem of integrity in each of many individual components, these components—often programmed independently of one another—must interact in precisely specified ways in order to be compatible. An example of what can happen otherwise was provided last year by the Chicago Board of Trade, which temporarily had to suspend activity on its electronic trading system for financial derivatives (called Project A) because of such a system-programming problem.¹⁶ Project A is a demonstration project being conducted by an exchange that is still mainly organized as an open-outcry trading pit. If this suspension had taken place on an exchange that relies primarily on electronic trading, as some of the world's principal exchanges already do and others envision doing soon, then there would have been an exchange-wide suspension of trading with potential implications beyond the exchange itself.

In the past, central banks and other financial intermediaries often have programmed idiosyncratic, proprietary systems suited to their individual needs. The critical need for this software to perform accurately and reliably, in view of the features that I have described above, makes such an approach increasingly risky and inordinately expensive as software becomes highly complex. The preferable approach is to synthesize a system by relying as far as possible on generic modules that are widely enough used to justify (and to share) the heavy cost of exhaustive testing, and that preferably have been used together in various combinations sufficiently often that there is a high degree of confidence in their compatibility. Besides mitigating in the first instance the problems of integrity that I have described, maintaining a system of components in widespread, current use helps to ensure that the most skilled technicians will be available (as both employees and contractors) to maintain the system and to make prompt, effective repairs when necessary.

Following this modular-design approach means depending more than previously on the general market for software and software-operated information services to meet information-technology needs. A caveat regarding this dependence has to do with the unusually high premium that financial system customers place on integrity and security. Constituting part of a niche market in this respect, the financial services industry may sometimes not be a priority customer of the software industry. The market for advanced encryption technology provides a case in point. The Digital Encryption System (DES) has been widely incorporated as a security measure in financial system software since its introduction in the 1970s. For most of that time, DES has been regarded as a commercially reasonable security measure for large-value transactions. Progressively through the 1990s, however, advances in code-breaking techniques have raised some doubt regarding the adequacy of DES encryption. A more secure encryption algorithm based on DES, the Triple Data Encryption Algorithm (TDEA, informally known as “triple DES”), has been regarded by experts for some time to offer a preferable level of protection.¹⁷ However, despite this situation having developed somewhat predictably as code-breaking research continued and triple DES having been identified early as a reasonable response to it, the current state of the market is such that conversion of a computer system to triple-DES encryption remains a costly and managerially challenging project.¹⁸

A parallel situation exists with respect to software integrity. For example, current industry efforts to ensure the interoperability essential to the modular design approach envisioned above may not be stringent enough to meet fully the needs of the financial system.¹⁹ The financial system is likely to look to central banks for leadership in working with the information technology industry and its regulators (including, perhaps, defense-related agencies charged with safeguarding communications and other economic infrastructure) to ensure that needs are met. Because the character of that industry is heavily affected by the special attributes of information technology as an economic good, bringing the needs of the financial system effectively to its attention is likely to require considerable exercise of judgment and creativity, as well as tenacity.²⁰

Central bank transparency

As I mentioned at the outset, the economic management of information includes design decisions regarding the structure of institutions, as well as decisions about the employment of electronic technology for

computing and communication. Central bank transparency is an issue to which both kinds of decision are relevant.

For purposes of this discussion, I call a central bank transparent to the extent that it makes public the information about itself that is relevant to the formulation and implementation of present and future monetary policy. Such information might include its objectives, its understanding (in terms of both broad concepts and specific formal models) of the structure economy, its knowledge about the current state of the economy, and its decision-making protocol.

This definition is intended to separate as clearly as possible the issue of transparency from the issue of intellectual decisiveness within the central bank itself. For example, if decision-makers within the central bank are confused or divided at a point in time regarding the significance of unexpected developments, then the public’s inability to attribute a coherent view of the economy to the central bank merely reflects the true situation of the central bank, not any lack of transparency.²¹

During the past decade or two, central banks have espoused transparency to a substantial extent. One reason may be that the electorate has grown to regard this as something for which the central bank is accountable, and that central bank independence is therefore politically dependent on transparency. Another reason is that central bankers have recognized that greater transparency may favorably affect the scope of action within which they can maintain credibility while responding to macroeconomic developments. This broader scope of action may make monetary policy more effective. I am not concerned here with the justification of transparency, however, but rather with the question of how to achieve it.

Some early research on this topic (for example, Canzoneri, 1985) modeled transparency in terms of disclosure by the central bank of its information regarding the economy. The advances in information technology that have been the focus of the article thus far make such a modeling perspective less convincing than it may have previously been. A central bank does possess some private information (for example, more timely access than the public to some economic statistics compiled by the government), but large corporations—particularly multinationals—presumably possess some information that the central bank lacks. Thus, on the whole, central banks do not seem unique in point of privileged access to information or to the judgment of sophisticated market participants. Where central banks may have been unique a generation ago was in possession of techniques and equipment for

sophisticated formal modeling and forecasting, which was the province of a small community of central bank experts and university researchers. Today such econometric expertise is widely available to the public. Moreover, in some economies, the dramatic growth of financial derivatives markets and the concurrent issuance of indexed and unindexed bonds (that are approximately comparable in other respects) have generated price information that is available to the general public and have facilitated the public's direct acquisition of accurate information about expectations, especially regarding inflation.²²

A more recent approach to analyzing transparency, taken by Faust and Svensson (1998), focuses on communication by the central bank of its objective. Faust and Svensson base their work on a modified version of a model of Cukierman and Meltzer (1986), according to which the central bank has a preferred solution to an inflation/employment tradeoff, and this preference is private information. They informally recognize that this assumption could be given more satisfactory foundations by assuming, as in Wallace (1984), that the public is heterogeneous and that monetary policy can work to the advantage of some sectors but to the disadvantage of others. The tradeoff that the central bank intends to make regarding the welfare of these sectors is its private information, which the public must infer from the subset of economic outcomes that it can observe.

My impression is that this focus on a private incentive is much closer to the gist of the actual problem of transparency than a focus on private knowledge of specific facts. Recall, however, that when I proposed a definition of transparency above, I mentioned two other domains of private information besides these two. One is the central bankers' understanding of the structure of the economy and the other is their protocol for reaching group decisions. Despite the wisdom of Faust and Svensson's decision to simplify their formal model by focusing on objectives rather than general understandings or decision protocols, transparency in these other domains is equally important and presents problems for central bankers that are at least as thorny. For example, if a central bank has a staff econometric model that is routinely discussed when monetary policy is set, should the model be described to the public and should its software even be disclosed in full? Whether or not such an initiative would do harm in any respect, I do not believe that it would give an accurate or helpful picture of the overall thinking of the monetary policy committee. The collective state of mind of such a committee would better be described by Paul Feyerabend's description

of the collective state of mind of a scientific community as "a whole set of partially overlapping, factually accurate, but mutually inconsistent theories."²³ How does one accurately and informatively disclose such a state of mind to the public? I can only hope to scratch the surface of this question in this article.

There is one asymmetry in Faust and Svensson's modeling approach that would disappear if a more thoroughly *game-theoretic* approach were to be taken. That is, they present credibility as an issue of the central bank's ability to make incentive-compatible disclosure of private information, while they present transparency as an issue of the extent to which the central bank's information regarding its own objectives (or, more generally, its type in the sense that I have discussed above) is private or public. In my view, this latter information is private and the public's ability to know it is highly dependent, exactly as in the case of information about central bank actions, on there being an institutional framework that gives the central bank an incentive for accurate and informative reporting.

Discussion of institutional design to enhance transparency tends to focus on specific proposals such as the prompt publication of minutes of meetings where policy is set. My sense is that such proposals rely for their effectiveness on more fundamental structural features of the central bank. To illustrate this idea, let me cite a structural feature of the Federal Reserve that I believe plays a most significant role in achieving transparency: its decentralized structure. There are 19 persons, the seven governors of the Federal Reserve Board and the 12 presidents of the Federal Reserve Banks, who participate directly in the deliberations of the Federal Open Market Committee (FOMC), which sets monetary policy.²⁴ A substantial part of the ongoing analytical support of FOMC decision-making is provided by the staffs of the Board of Governors and the Federal Reserve Bank of New York. However, the fully independent participation of each Reserve Bank president is buttressed by the president's status as the head of a separately chartered corporation that comprises, among other things, a research department under the unilateral control of that president. The autonomy that is built into this structure has produced, over time, open discussion of a number of policy foundations and alternatives that I believe might have received less or later exposure in a more centralized institutional framework.

Several important examples from recent decades support this case. Beginning in the 1960s, the Federal Reserve Bank of St. Louis conducted a sustained program of research and advocacy regarding the control

of monetary aggregates as a basis for conducting monetary policy.²⁵ In the 1970s and 1980s, the Federal Reserve Bank of Minneapolis played a significant role in developing *general equilibrium* monetary models for policy analysis as an alternative to the macroeconomic modeling approach that was then dominant in the Federal Reserve.²⁶ In the early 1990s, the Federal Reserve Bank of Cleveland persistently made a case that the benefits of bringing inflation under control would not be fully garnered until exact price stability had been achieved.²⁷ These essays in analysis and persuasion have been both more vigorous and more open to public scrutiny than I believe they would have been if they had been led by policymakers of equivalent seniority, but operating within a more hierarchically organized central bank. In all three cases, the advocates of heterodox positions within the central bank have had to depend heavily on informed public opinion, and particularly on the endorsement of economists in the academic community, to affirm the correctness of their views. Thus, the decentralized design of the U.S. central banking system systematically forces policy debate out into the open marketplace of ideas, to the benefit of both the transparency of the Federal Reserve System and the intellectual caliber of the discussion. The history of the three initiatives that I have mentioned, and of others as well, suggests that this process succeeds in identifying and evaluating significant new ideas and, where merited, progressively infusing them into the policymaking of the central bank as a whole, albeit usually not in the uncompromising form that they initially tend to be proposed. In my view, this sort of institutional design for the central bank is an important complement to the various, specific regulations (regarding, for example, the exact timing and format of public release of minutes of policy-setting meetings) that are usually recommended as means to achieve transparency and to ensure that monetary policy is publicly accountable.

Other design approaches, adopted by various central banks in recent years, have analogous roles in

providing transparency. The common feature of these approaches is that, rather than attempting to achieve transparency by mandate, they set in place systems of incentives that result in an institutional culture of transparency.²⁸ Both a conducive culture and a clear public mandate have a place in achieving transparency. Indeed, for the central bank to have an appropriate institutional culture is probably a necessary condition for a mandate to be effective.

Conclusion

Recent, dramatic innovations in the economic management of information, and particularly their application in the payments system, might seem potentially to change the nature of central banking. On close examination, however, these developments do not significantly change the role or responsibilities of a central bank. They do not render obsolete the established body of knowledge regarding what constitutes a well designed central bank and sound central banking practice.

Similarly, intellectual advances in understanding how organizations should optimally be designed reinforce established thinking about how a central bank should be designed to achieve transparency. Indeed, these advances provide a clearer understanding of how the decentralized structure of the Federal Reserve System contributes to the effectiveness of the U.S. central bank and to the public welfare.

The one area where innovations in information technology do seem to call for new understanding is in the involvement of central banks with the technology itself. Such involvement is required to discharge both oversight and operational responsibilities. On behalf of the financial system, as well as on its own behalf, a central bank must manage problems that are rooted in the structure of the information-technology industry. Adept management is required to maintain the integrity and security of a financial system that, because of its scope and complexity, is critically dependent on information technology for its functioning.

NOTES

¹Money issued by the central bank is known as *outside money*. Commercial banks and other such depository institutions also issue money, in effect, when they make loans. This is known as *inside money*. A requirement that depository institutions must hold reserves of outside money constrains their ability to create inside money. Reserve requirements in the U.S. and some other countries are *deposit reserves* based on the value of deposits that a depository institution holds, and in other countries are *clearing balances* based on the value of payments that a depository institution makes on behalf of its depositors. In this article, “money” means outside money unless otherwise indicated, and “reserves”

is used as a generic term for either deposit reserves or clearing balances.

²E-money refers to a family of payment methods that include stored-value cards and “Internet cash” designed for widespread use. Payment methods designed for convenient purchasing from a single seller, such as the fare cards issued by some public transit authorities, are not within the meaning that is usually intended.

³The CLS system is described in Bank for International Settlements (1998).

⁴De Santis (1998) describes the proposed system and its risk-management implications. Marjanovic (1998) also provides a brief description.

⁵A negotiable instrument is one that has a particular, named individual as its beneficiary, but that allows that beneficiary to designate another person as beneficiary instead (typically, as payment for a good or service received from the new beneficiary). A bearer security is a financial instrument, such as currency, whose beneficiary is whoever happens to possess it. Some types of e-money differ from a literal bearer security in point of requiring proof of ownership beyond physical possession. That difference is not material to the analogy drawn here.

⁶That is, a bearer security issued by a bank and redeemable for coin or other legal money. Wallace (1986) and Summers and Gilbert (1996) have previously emphasized this analogy.

⁷Friedman (1999) and King (1999) suggest that extensive use of information technology might make it possible in principle for the private sector to operate a comprehensive settlement network that would be wholly outside the influence of the central bank. In that case, my premise would be violated. The gist of my argument in this section is that, although it might seem that being able to settle large gross payments with much smaller net payments is tantamount to the situation that Friedman and King have in mind, the implications for monetary policy may be materially different.

⁸Bank for International Settlements (1996) reflects some of that discussion.

⁹The model is an elaboration of a cash-in-advance model of Lucas and Stokey (1987) in which, for each trader, some goods are *credit goods* that are exempt from the cash-in-advance constraint that holds for the remaining *cash goods*. The elaboration is to endogenize the cash/credit distinction as explained here. Such models were introduced by Schreft (1992) and Aiyagari, Braun, and Eckstein (1998).

¹⁰This foregone interest is *seignorage* that is captured by the government, which would have to issue interest-bearing debt to finance expenditure if people would not accept money. Seignorage is thus an implicit tax on holding money.

¹¹This is Roy's identity; see Deaton and Muellbauer (1980), p. 40. This principle is highly intuitive. For example, if someone purchases five daily newspapers and one weekly newsmagazine a week, then a penny increase in the price of a newspaper hurts five times as much as a penny increase in the price of a magazine. This is evidently true if consumption does not change. If the reader cuts down to four newspapers a week, then he was getting just one penny's worth of utility from the fifth paper beyond what alternative expenditure of its price would have yielded (since he elected to give it up when an extra penny was charged), so (on the simplifying assumption that utility is measured in whole penny's-worth units) he still loses a penny's worth of utility despite changing his budget allocation.

¹²Freeman (1996a, b, and 1999) and Green (1997) analyze central bank operations, and also clearinghouse operations closely akin to netting, in this way.

¹³Such a responsibility is widely conferred to, and considered an appropriate role for, central banks. Consensus to this effect is reflected, for example, in a series of documents issued under the auspices of the Bank for International Settlements during the past decade. Payment arrangements operated by private financial intermediaries (either directly or via jointly owned subsidiaries) evidently cannot be supervised in isolation from the sponsoring

intermediaries themselves. Therefore, oversight of such arrangements involves coordination between the central bank and the supervision authorities for various types of intermediaries.

¹⁴Statements of Paul A. Volcker, Chairman, Board of Governors of the Federal Reserve System, and J. Carter Bacot, Chairman and Chief Executive Officer of the Bank of New York and the Bank of New York Company, Inc., before the Subcommittee on Domestic Monetary Policy of the Committee on Banking, Finance, and Urban Affairs, House of Representatives, December 12, 1985. Reprinted in U.S. Congress (1986).

¹⁵Statement of Paul A. Volcker, Chairman, Board of Governors of the Federal Reserve System, before the Subcommittee on Domestic Monetary Policy of the Committee on Banking, Finance, and Urban Affairs, House of Representatives, December 12, 1985. Reprinted in U.S. Congress (1986).

¹⁶Chicago Board of Trade (1999).

¹⁷In 1998, the Accredited Standards Committee X9 on Financial Services, a U.S. financial services industry committee working under the aegis of the American National Standards Institute (ANSI), adopted standard ANSI X9.52, which specifies triple DES as an interim encryption method for large-value financial transactions until a more durable method can be developed. In 1999, the X9 Committee issued technical guideline TG-25-1999, which expresses a consensus that (single) DES encryption no longer provides adequate security for large-value transactions. An analogous guideline for U.S. government applications and public recommendation for nongovernmental applications, "Data encryption standard (DES)," Federal Information Processing Standards (FIPS) Publication 46-3, was issued by the U.S. Department of Commerce/National Institute of Standards and Technology (NIST) in 1999. This guideline designates triple DES as an encryption algorithm of choice and permits DES for legacy systems only. The NIST is also in the process of adopting an Advanced Encryption Standard that will co-exist with, and eventually supplant, triple DES.

¹⁸To provide adequate electronic security, conversion to triple DES must be done in conjunction with other measures such as setting up a cryptographic key-management system. For non-U.S. entities, a further complication recognized by NIST FIPS-46-3 is that export of encryption systems deemed to provide commercially reasonable security for large-value financial applications is subject to U.S. export-control regulation.

¹⁹Summers (1999) raises this issue.

²⁰Arrow (1974) provides a classic introduction to the issues of market structure engendered by characteristics of information-related industries.

²¹Transparency is relevant in other contexts besides monetary policy, but I have qualified the definition in this respect to screen off issues that involve special considerations (such as whether "constructive ambiguity" about the extent of the central bank's willingness to provide emergency credit is a justifiable strategy to deter implicitly subsidized risk-taking).

²²Roughly speaking, the interest rate premium of an unindexed bond above an indexed bond of the same maturity provides a measure of expected inflation from the present to the maturity date. Techniques to extract information regarding expectations from asset-price data are surveyed by Soderlind and Svensson (1997).

²³Feyerabend (1978), p. 39.

²⁴All but one of the Reserve Bank presidents are voting members only in rotation, but their participation in deliberations is continuous.

²⁵See Andersen and Carlson (1974).

²⁶See Miller (1994), which is a collection of papers reprinted from the Federal Reserve Bank of Minneapolis, *Quarterly Review*.

²⁷See Gavin (1991).

²⁸Having such incentive systems in place is a very helpful means to attract capable, principled, intellectually independent persons to serve on the governing board of the central bank. It is also helpful to guarantee the ability of the governing board to hire and retain staff with those characteristics. Perception of the high character and ability of the central bank leadership and staff seems to contribute materially to public support for central bank independence.

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