Monetary Policy in the Information Economy

Michael Woodford

Improvements in information processing technology, and in communications are likely to transform many aspects of economic life, but likely no sector of the economy will be more profoundly affected than the financial sector. Financial markets are rapidly becoming better connected with one another, the costs of trading in them are falling, and market participants now have access to more information more quickly about developments in the markets and in the economy more broadly. As a result, opportunities for arbitrage are exploited and eliminated more rapidly. The financial system can be expected to become more efficient, in the sense that the dispersion of valuations of claims to future payments across different individuals and institutions is minimized. For familiar reasons, this should be generally beneficial for the allocation of resources in the economy.

Some, however, fear that the job of central banks will be complicated by improvements in the efficiency of financial markets, or even that the ability of central banks to influence the markets may be eliminated altogether. This suggests a possible conflict between the aim of increasing *microeconomic* efficiency—the efficiency with which resources are correctly allocated among competing uses at a point in time—and that of preserving *macroeconomic* stability, through prudent central-bank regulation of the overall volume of nominal expenditure.

Here, I consider two possible grounds for such concern. I first consider the consequences of increased information on the part of market participants about monetary policy actions and decisions. According to the view that the effectiveness of monetary policy is enhanced by, or even entirely dependent upon, the ability of central banks to surprise the markets, there might be reason to fear that monetary policy will be less effective in the information economy. I then consider the consequences of financial innovations tending to reduce private-sector demand for the monetary base. These include the development of techniques that allow financial institutions to more efficiently manage their customers' balances in accounts subject to reserve requirements and their own balances in clearing accounts at the central bank, so that a given volume of payments in the economy can be executed with a smaller quantity of central-bank balances. And somewhat more speculatively, some argue that "electronic money" of various sorts may soon provide alternative means of payment that can substitute for those currently supplied by central banks. It may be feared that such developments can soon eliminate what small leverage central banks currently have over the private economy, so that again monetary policy will become ineffective.

I shall argue that there is little ground for concern on either count. The effectiveness of monetary policy is, in fact, dependent neither upon the ability of central banks to fool the markets about what they do, nor upon the manipulation of significant market distortions, and central banks should continue to have an important role as guarantors of price stability in a world where markets are nearly frictionless and the public is well-informed. Indeed, I shall argue that monetary policy can be even more effective in the information economy, by allowing central banks to use signals of future policy intentions as an additional instrument of policy, and by tightening the linkages between the interest rates most directly affected by central-bank actions and other market rates.

However, improvements in the efficiency of the financial system may have important consequences, both for the specific operating procedures that can most effectively achieve banks' short-run targets, and for the type of decision procedures for determining the operating targets that will best serve their stabilization objectives. In both respects, the U.S. Federal Reserve might well consider adopting some of the recent innovations pioneered by other central banks. These include the use of standing facilities as a principal device through which overnight interest rates are controlled, as is currently the case in countries like Canada and New Zealand; and the apparatus of explicit inflation targets, forecast-targeting decision procedures, and published Inflation Reports as means of communicating with the public about the nature of central-bank policy commitments, as currently practiced in countries like the U.K., Sweden, and New Zealand.

Improved information about central bank actions 1

One possible ground for concern about the effectiveness of monetary policy in the information economy derives from the belief that the effectiveness of policy actions is enhanced by, or even entirely dependent upon, the ability of central banks to surprise the markets. Views of this kind underlay the preference, commonplace among central bankers until quite recently, for a considerable degree of secrecy about their operating targets and actions, to say nothing of their reasoning processes and their intentions regarding future policy. Improved efficiency of communication among market participants, and greater ability to process large quantities of information should make it increasingly unlikely that central bank actions can remain secret for long. Wider and more rapid dissemination of analyses of economic data, of statements by central-bank officials, and of observable patterns in policy actions are likely to improve markets' ability to forecast central banks' behavior as well, whether banks like this or not. In practice, these improvements in information dissemination have coincided with increased political demands for accountability from public institutions of all sorts in many of the more advanced economies, and this had led to widespread demands for greater openness in central-bank decision-making.

As a result of these developments, the ability of central banks to surprise the markets, other than by acting in a purely erratic manner (that obviously cannot serve their stabilization goals), is likely to be reduced. Should we expect this to reduce the ability of central banks to achieve their stabilization goals? Should central banks seek to delay these developments to the extent that they are able?

I shall argue that such concerns are misplaced. There is little ground to believe that secrecy is a crucial element in effective monetary policy. To the contrary, more effective signaling of policy actions and policy targets, and above all, improvement of the ability of the private sector to anticipate future central bank actions should *increase* the effectiveness of monetary policy, and for reasons that are likely to become even more important in the information economy.

The effectiveness of anticipated policy 1.1

One common argument for the greater effectiveness of policy actions that are not anticipated in advance asserts that central banks can have a larger effect on market prices through trades of modest size if these trades are not signaled in advance. This is the usual justification given for the fact that official interventions in foreign-exchange markets are almost invariably secret, not being confirmed even after the interventions have taken place. But a similar argument might be made for maximizing the impact of central banks' open-market operations upon domestic interest rates, especially by those who feel that the small size of central-bank balance sheets relative to the volume of trade in money markets makes it implausible that central banks should be able to have much effect upon market prices. The idea, essentially, is that unanticipated trading by the central bank should move market rates by more, owing to the imperfect liquidity of the markets. Instead, if traders are widely able to anticipate the central bank's trades in advance, a larger number of counter-parties should be available to trade with the bank, so that a smaller change in the market price will be required in order for the market to absorb a given change in the supply of a particular instrument.

But such an analysis assumes that the central bank better achieves its objectives by being able to move market yield more, even if it does so by exploiting temporary illiquidity of the markets. But the temporarily greater movement in market prices that is so obtained occurs only because these prices are temporarily less well coupled to decisions being made outside the financial markets. Hence, it is not at all obvious that any actual increase in the effect of the central bank's action upon the economy—upon the things that are actually relevant to the bank's stabilization goals—can be purchased in this way.

The simple model presented in the Appendix may help to illustrate this point. In this model, the economy consists of a group of households that choose a quantity to consume and then allocate their remaining wealth between money and bonds. When the central bank conducts an open-market operation, exchanging money for bonds, it is assumed that only a fraction γ of the households are able to participate in the bond market (and so to adjust their bond holdings relative to what they had previously chosen). I assume that the rate of participation in the end-of-period bond market could be increased by the central bank by signaling in advance its intention to conduct an open-market operation, that will, in general, make it optimal for a household to adjust its bond portfolio. The question posed is whether "catching the markets off guard" in order to keep the participation rate γ small can enhance the effectiveness of the open-market operation.

It is shown that the equilibrium bond yield *i* is determined by an equilibrium condition of the form.[1]

$$d(i) = (\Delta M) / \gamma,$$

where ΔM is the per capita increase in the money supply through open-market bond purchases, and the function $d(i)$ indicates the desired increase in bond holding by each household that participates in the end-of-period trading, as a function of the bond yield determined in that trading. The smaller is γ, the larger the portfolio shift that each participating household must be induced to accept, and so the larger the change in the equilibrium bond yield *i* for a given size of open-market operation ΔM. This validates the idea that surprise can increase the central bank's ability to move the markets.

But this increase in the magnitude of the interest-rate effect goes hand in hand with a reduction in the fraction of households whose expenditure decisions are *affected* by the interest-rate change. The consumption demands of the fraction $1-\gamma$ of households not participating in the end-of-period bond market are independent of i, even if they are assumed to make their consumption-saving decision only after the open-market operation. (They may *observe* the effect of the central bank's action upon bond yields, but this does not matter to them, because a change in their consumption plans cannot change their bond holdings.) If one computes aggregate consumption expenditure C, aggregating the consumption demands of the γ households who participate in the bond trading and the $1-\gamma$ who do not, then the partial derivative $\delta C/\delta \Delta M$ is a positive quantity that is *independent* of γ. Thus, up to a linear approximation, reducing participation in the end-of-period bond trading does not increase the effects of open-market purchases by the central bank upon aggregate demand, even though it increases the size of the effect on market interest rates.

It is sometimes argued that the ability of a central bank (or other authority, such as the Treasury) to move a market price through its interventions is important for reasons unrelated to the direct effect of that price movement on the economy; it is said, for example, that such interventions are important mainly in order to a "send a signal" to the markets, and presumably the signal is clear only insofar as a non-trivial price movement can be caused.[2] But while it is certainly true that effective signaling of government policy intentions is of great value, it would be odd to lament improvements in the timeliness of private-sector information about government policy actions on that ground. Better private-sector information about central-bank actions and deliberations should make it easier, not harder, for central banks to signal their intentions, as long as they are clear about what those intentions are.

Another possible argument for the desirability of surprising the markets derives from the well-known explanation for central-bank "ambiguity" proposed by Cukierman and Meltzer (1986)[3] These authors assume, as in the "New Classical" literature of the 1970s, that deviations of output from potential are proportional to the unexpected component of the current money supply. They also assume that policymakers wish to increase output relative to potential, and to an extent that varies over time as a result of real disturbances. Rational expectations preclude the possibility of an equilibrium in which money growth is higher than expected (and, hence, in which output is higher than potential) on *average*. However, it is possible for the private sector to be surprised in this way at some times, as long as it also happens sufficiently often that money growth is *less* than expected. This bit of leverage can be used to achieve stabilization aims if it can be arranged for the positive surprises to occur at times when there is an unusually strong desire for output greater than potential (for example, because the degree of inefficiency of the "natural rate" is especially great), and the negative surprises at times when this is less crucial. This is possible, in principle, if the central bank has information about the disturbances that increase the desirability of high output that is not shared with the private sector. This argument provides a reason why it may be desirable for the central bank to conceal information that it has about current economic conditions that are relevant to its policy choices. It even provides a reason why a central bank may prefer to conceal the actions that it has taken (for example, what its operating target has been), insofar as there is serial correlation in the disturbances about which the central bank has information not available to the public, so that revealing the bank's *past* assessment of these disturbances would give away some of its *current* informational advantage as well.

However, the validity of this argument for secrecy about central-bank actions and central-bank assessments of current conditions depends upon the simultaneous validity of several strong assumptions. In particular, it depends upon a theory of aggregate supply according to which surprise variations in monetary policy have an effect that is undercut if policy can be anticipated.[4] While this hypothesis is familiar from the literature of the 1970s, it has not held up well under further scrutiny. Despite the favorable early result of Barro (1977), the empirical support for the hypothesis that "only unanticipated money matters" was challenged in the early 1980s (notably, by Barro and Hercowitz, 1980, and Boschen and Grossman, 1982), and the hypothesis has largely been dismissed since then.

Nor is it true that this particular model of the real effects of nominal disturbances is uniquely consistent with the hypotheses of rational expectations or optimizing behavior by wage- and price-setters. For example, a popular simple hypothesis in recent work has been a model of optimal price-setting with random intervals between price changes, originally proposed by Calvo (1983).[5] This model leads to an aggregate-supply relation of the form

$$\pi_t = \kappa\left(y_t - y_t^n\right) + \beta E_t \pi_{t+1}, \qquad (1.1)$$

where π_t is the rate of inflation between dates t–1 and t, y_t is the log of real GDP, y_t^n is the log of the "natural rate" of output (equilibrium output with flexible wages and prices, here a function of purely exogenous real factors), $E_t\pi_{t+1}$ is the expectation of future inflation conditional upon period-t public information, and the coefficients $\kappa>0, 0<\beta<1$ are constants. As with the familiar "New Classical" specification implicit in the analysis of Cukierman and Meltzer, which we may write using similar notation as

$$\pi_t = \kappa\left(y_t - y_t^n\right) + E_{t-1}\pi_t, \qquad (1.2)$$

this is a short-run "Phillips curve" relation between inflation and output that is shifted both by exogenous variations in the natural rate of output and by endogenous variations in expected inflation.

However, the fact that *current* expectations of *future* inflation matter for (1.1), rather than past expectations of current inflation as in (1.2), makes a crucial difference for present purposes. Equation (1.2) implies that in any rational-expectations equilibrium,

$$E_{t-1}\left(y_t - y_t^n\right) = 0,$$

so that output variations due to monetary policy (as opposed to real disturbances reflected in y_t^n) must be purely unforecastable a period in advance. Equation (1.1) has no such implication. Instead, this relation implies that both inflation and the output at any date t depend solely upon (i) current and expected future nominal GDP, relative to the period $t-1$ price level, and (ii) the current and expected future natural rate of output, both conditional upon public information at date t. The way in which output and inflation depend upon these quantities is *completely independent* of the extent to which any of the information available at date t may have been anticipated at earlier dates. Thus, signaling in advance the way that monetary policy seeks to affect the path of nominal expenditure does not eliminate the effects upon real activity of such policy—it does not weaken them at all!

Of course, the empirical adequacy of the simple "New Keynesian Phillips Curve" (1.1) has also been subject to a fair amount of criticism. However, it is not as grossly at variance with empirical evidence as is the "New Classical" specification.[6] Furthermore, most of the empirical criticism focuses upon the absence of any role for lagged wage and/or price inflation as a determinant of current inflation in this specification. But if one modifies the aggregate-supply relation (1.1) to allow for inflation inertia—along the lines of the well-known specification of Fuhrer and Moore (1995), the "hybrid model" proposed by Gali and Gertler (1999), or the inflation-indexation model proposed by Christiano et al. (2001)—the essential argument is unchanged. In these specifications, it is current inflation relative to recent past inflation that determines current output relative to potential; but inflation acceleration should have the same effects whether anticipated in the past or not.

Some may feel that a greater impact of unanticipated monetary policy is indicated by comparisons between the reactions of markets (for example, stock and bond markets) to changes in interest-rate operating targets that are viewed as having surprised many market participants and reactions to those that were widely predicted in advance. For example, the early study of Cook and Hahn (1989) found greater effects upon Treasury yields of U.S. Federal Reserve changes in the federal funds rate operating target during the 1970s at times when these represented a change in direction relative to the most recent move, rather than continuation of a series of target changes in the same direction; these might plausibly have been regarded as the more unexpected actions. More recent studies such as Bomfim (2000) and Kuttner (2001) have documented larger effects upon financial markets of unanticipated target changes using data from the fed funds futures market to infer market expectations of future Federal Reserve interest-rate decisions.

But these quite plausible findings in no way indicate that the Fed's interest-rate decisions affect financial markets only insofar as they are unanticipated. Such results only indicate that when a change in the Fed's operating target is widely anticipated in advance, market prices will already reflect this information *before* the day of the actual decision. The actual change in the Fed's target, and the associated change at around the same time in the federal funds rate itself, makes relatively little difference insofar as Treasury yields and stock prices depend upon market expectations of the average level of overnight rates over a horizon extending substantially into the future, rather than upon the *current* overnight rate alone. Information that implies a future change in the level of the funds rate should affect these market prices immediately, even if the change is not expected to occur for weeks; while these prices should be little affected by the fact that a change has already occurred, as opposed to being expected to occur (with complete confidence) in the following week. Thus, rather than indicating that the Fed's interest-rate decisions matter only when they are not anticipated, these findings provide evidence that anticipations of future policy *matter*—and that market expectations are more sophisticated than a mere extrapolation of the current federal funds rate.

Furthermore, even if one were to grant the empirical relevance of the "New Classical" aggregate-supply relation, the Cukierman-Meltzer defense of central-bank ambiguity also depends upon the existence of a substantial information advantage on the part of the central bank about the times at which high output relative to potential is particularly valuable. This might seem obvious, insofar as it might seem that the state in question relates to the aims of the government, about which the government bureaucracy should always have greater insight. But if we seek to design institutions that improve the general welfare, we should have no interest in increasing the ability of government institutions to pursue idiosyncratic objectives that do not reflect the interests of the public. Thus, the only relevant grounds for variation in the desired level of output relative to potential should be ones that relate to the economic efficiency of the natural rate of output (which may, indeed, vary over time, due, for example, to time variation in market power in goods and/or labor markets). Yet, government entities have no inherent advantage at assessing such states. In the past, it may have been the case that central banks could produce better estimates of such states than most private institutions, thanks to their large staffs of trained economists and privileged access to government statistical offices. However, in coming decades, it seems likely that the dissemination of accurate and timely information about economic conditions to market participants should increase. If the central bank's informational advantage with regard to the current severity of market distortions is eroded, there will be no justification (even according to the Cukierman-Meltzer model) for seeking to preserve an informational advantage with regard to the bank's intentions and actions.

Thus, there seems little ground to fear that erosion of central banks' informational advantage over market participants, to the extent that one exists, should weaken banks' ability to achieve their legitimate stabilization objectives. Indeed, there is considerable reason to believe that monetary policy should be even more effective under circumstances of improved private-sector information. This is because successful monetary policy is not so much a matter of effective control of overnight interest rates, or even of effective control of changes in the CPI, so much as of affecting in a desired way the evolution of market *expectations* regarding these variables. If the beliefs of market participants are diffuse and poorly informed, this is difficult, and monetary policy will necessarily be a fairly blunt instrument of stabilization policy; but in the information economy, there should be considerable scope for the effective use of the traditional instruments of monetary policy.

It should be rather clear that the current level of overnight interest rates *as such* is of negligible importance for economic decision-making; if a change in the overnight rate were thought to imply only a change in the cost of overnight borrowing for that one night, then even a large change (say, a full percentage point increase) would make little difference to anyone's spending decisions. The effectiveness of changes in central-bank targets for overnight rates in affecting spending decisions (and, hence, ultimately pricing and employment decisions) is wholly dependent upon the impact of such actions upon other financial-market prices, such as longer-term interest rates, equity prices, and exchange rates. These are plausibly linked, through arbitrage relations, to the short-term interest rates most directly affected by central-bank actions; but it is the *expected future path* of short-term rates over coming months and even years that should matter for the determination of these other asset prices, rather than the current level of short-term rates by itself.

The reason for this is probably fairly obvious in the case of longer-term interest rates; the expectations theory of the term structure implies that these should be determined by expected future short rates. It might seem, however, that familiar interest-rate parity relations should imply a connection between exchange rates and short-term interest rates. It should be noted, however, that interest-rate parity implies a connection between the interest-rate differential and the rate of *depreciation* of the exchange rate, not its absolute level, whereas it is the level that should matter for spending and pricing decisions. Let us write this relation in the form

$$e_t = e_{t+1} + \left(i_t - E_t\pi_{t+1}\right) - \left(i_t^* - E_t\pi_{t+1}^*\right) + \psi_t, \tag{1.3}$$

where e_t is the real exchange rate, i_t and i_t^* the domestic and foreign short-term nominal interest rates, π_t and π_t^* the domestic and foreign inflation rates, and ψ_t a "risk premium" here treated as exogenous. If the real exchange rate fluctuates over the long run around a constant level $\bar{e}$, it follows that we can "solve forward" (1.3) to obtain

$$e_t = \bar{e} + \sum_{j=0}^{\infty} E_t\left(i_{t+j} - \pi_{t+j+1} - \bar{r}\right) \sum_{j=0}^{\infty} E_t\left(i_{t+j}^* - \pi_{t+j+1}^* - \psi_{t+j} - \bar{r}\right), \tag{1.4}$$

where $\bar{r}$ is the long-run average value of the term $r_t^* \equiv i_t^* - E_t\pi_{t+1} - \psi_t$. Note that in this solution, a change in current expectations regarding the short-term interest rate at any future date should move the exchange rate as much as a change of the same size in the current short-term rate.

Of course, what this means is that the most effective way of moving the exchange rate, without violent movements in short-term interest rates, will be to change expectations regarding the level of interest rates over a substantial period of time.

Similarly, it is correct to argue that intertemporal optimization ought to imply a connection between even quite short-term interest rates and the timing of expenditure decisions of all sorts. However, the Euler equations associated with such optimization problems relate short-term interest rates not to the level of expenditure at that point in time, but rather to the expected rate of change of expenditure. For example, (a log-linear approximation to) the consumption Euler equation implied by a standard representative-household model is of the form

$$c_t = E_t c_{t+1} - \sigma\left(i_t - E_t \pi_{t+1} - \rho_t\right), \qquad (1.5)$$

where c_t is the log of real consumption expenditure, ρ_t represents exogenous variation in the rate of time preference, and $\sigma > 0$ is the intertemporal elasticity of substitution. Many standard business-cycle models furthermore imply that long-run expectations

$$\bar{c}_t \equiv \lim_{T \to \infty} E_t\left[c_T - g(T - t)\right],$$

where g is the constant long-run growth rate of consumption, should be independent of monetary policy (being determined solely by population growth and technical progress, here treated as exogenous). If so, we can again "solve forward" (1.5) to obtain

$$c_t = \bar{c}_t - \sigma \sum_{j=0}^{\infty} E_t\left(i_{t+j} - \pi_{t+j} - \rho_{t+j} - \sigma^{-1} g\right). \qquad (1.6)$$

Once more, we find that current expenditure should depend mainly upon the expected future path of short rates, rather than upon the current level of these rates.[7] Woodford (2001, chap. 4) similarly shows that optimizing investment demand (in a neoclassical model with convex adjustment costs, but allowing for sticky product prices) is a function of a distributed lead of expected future short rates, with nearly constant weights on expected short rates at all horizons.

Thus, the ability of central banks to influence expenditure, and hence pricing, decisions is critically dependent upon their ability to influence market expectations regarding the future path of overnight interest rates, and not merely their current level. Better information on the part of market participants about central-bank actions and intentions should increase the degree to which central-bank policy decisions can actually affect these expectations, and so increase the effectiveness of monetary stabilization policy. Insofar as the significance of current developments for future policy are clear to the private sector, markets can, to a large extent, "do the central bank's work for it," in that the actual changes in overnight rates required to achieve the desired changes in incentives can be much more modest when expected future rates move as well.

There is evidence that this is already happening, as a result both of greater sophistication on the part of financial markets and greater transparency on the part of central banks, the two developing in a sort of symbiosis with one another. Blinder et al. (2001, p. 8) argue that in the period from early 1996 through the middle of 1999, one could observe the U.S. bond market moving in response to macroeconomic developments that helped to stabilize the economy, despite relatively little change in the level of the federal funds rate, and suggest that this reflected an improvement in the bond market's ability to forecast Fed actions before they occur. Statistical evidence of increased forecastability of Fed policy by the markets is provided by Lange et al. (2001), who show that the ability of Treasury bill yields to predict changes in the federal funds rate some months in advance has increased since the late 1980s.

The behavior of the funds rate itself provides evidence of a greater ability of market participants to anticipate the Fed's future behavior. It is frequently observed now that announcements of changes in the Fed's operating target for the funds rate (made through public statements immediately following the Federal Open Market Committee meeting that decides upon the change, under the procedures followed since February 1994) have an immediate effect upon the funds rate, even though the Trading Desk at the New York Fed does not conduct open market operations to alter the supply of Fed balances until the next day at the soonest (Meulendyke, 1998; Taylor, 2001). This is sometimes called an "announcement effect." Taylor (2001) interprets this as a consequence of intertemporal substitution (at least within a reserve maintenance period) in the demand for reserves, given the forecastability of a change in the funds rate once the Fed *does* have a chance to adjust the supply of Fed balances in a way consistent with the new target. Under this interpretation, it is critical that the Fed's announced policy targets are taken by the markets to represent credible signals of its future behavior; given that they are, the desired effect upon interest rates can largely occur even before any actual trades by the Fed.

Demiralp and Jorda (2001b) provide evidence of this effect by regressing the deviation between the actual and target federal funds rate on the previous two days' deviations, and upon the day's change in the target (if any occurs). The regression coefficient on the target change is substantially less than one (indicating adjustment of the funds rate in the desired direction on the day of the target change), and is smaller since 1994 (on the order of .4) than in the period 1984-1994 (nearly .6). This suggests that the ability of the markets to understand the consequences of FOMC decisions for movements in the funds rate has improved since the Fed's introduction of explicit announcements of its target rate, though it was non-negligible even before this. Of course, this sort of evidence indicates forecastability of Fed actions only over very short horizons (a day or two in advance), and forecastability over such a short time does not in itself help much to influence spending and pricing decisions. Still, the "announcement effect" provides a simple illustration of the principle that anticipation of policy actions in advance is more likely to *strengthen* the intended effects of policy, rather than undercutting them as the previous view would have it. In the information economy, it should be easier for the announcements that central banks choose to make regarding their policy intentions to be quickly disseminated among and digested by market participants. And to the extent that this is true, it should provide central banks with a powerful tool through which to better achieve their stabilization goals.

Consequences for the conduct of policy *1.2*

We have argued that improved private-sector information about policy actions and intentions will not eliminate the ability of central banks to influence spending and pricing decisions. However, this does not mean that there are no consequences for the effective conduct of monetary policy of increased market sophistication about such matters. There are several lessons to be drawn, which are relevant to the situations of the leading central banks even now, but which should be of only greater importance as information processing improves.

One is that *transparency is valuable* for the effective conduct of monetary policy. It follows from our above analysis that being able to count upon the private sector's correct understanding of the central bank's current decisions and future intentions increases the precision with which a central bank can, in principle, act to stabilize both prices and economic activity. We have argued that in the information economy, improved private-sector information is inevitable; but central banks can obviously facilitate this as well, though striving better to explain their decisions to the public. The more sophisticated markets become, the more scope there will be for communication about even subtle aspects of the bank's decisions and reasoning, and it will be desirable for central banks to take advantage of this opportunity.

In fact, this view has become increasingly widespread among central bankers over the past decade.[8] In the U.S., the Fed's degree of openness about its funds-rate operating targets has notably increased under Alan Greenspan's tenure as chairman.[9] In some other countries, especially inflation-targeting countries, the increase in transparency has been even more dramatic. Central banks such as the Bank of England, the Reserve Bank of New Zealand and the Swedish Riksbank are publicly committed not only to explicit medium-run policy targets, but even to fairly specific decision procedures for assessing the consistency of current policy with those targets, and to the regular publication of Inflation Reports that explain the bank's decisions in this light.

The issue of what exactly central banks should communicate to the public is too large a question to be addressed in detail here; Blinder et al. (2001) provide an excellent discussion of many of the issues. I will note, however, that from the perspective suggested here, what is important is not so much that the central bank's deliberations themselves be public, as that the bank give clear signals about what the public should expect it to do in the future. The public needs to have as clear as possible an understanding of the *rule* that the central bank follows in deciding what it does. Inevitably, the best way to communicate about this will be by offering the public an explanation of the decisions that have already been made; the bank itself would probably not be able to describe how it might act in all conceivable circumstances, most of which will never arise. But it is important to remember that the goal of transparency should be to make the central bank's behavior more systematic, and to make its systematic character more evident to the public—not the exposure of "secrets of the temple" as a goal in itself.

For example, discussions of transparency in central banking often stress such matters as the publication of minutes of deliberations by the policy committee, in as prompt and as unedited a form as possible. Yet, it is not clear that provision of the public with full details of the differences of opinion that may be expressed before the committee's eventual decision is reached really favors public understanding of the systematic character of policy. Instead, this can easily distract attention to apparent conflicts within the committee, and to uncertainty in the reasoning of individual committee members, which may reinforce skepticism about whether there is any "policy rule" to be discerned. Furthermore, the incentive provided to individual committee members to speak for themselves rather than for the institution may make it harder for the members to subordinate their individual votes to any systematic commitments of the institution, thus making policy less rule-based in fact, and not merely in perception.

More to the point would be an increase in the kind of communication provided by the Inflation Reports. These reports do not pretend to give a blow-by-blow account of the deliberations by which the central bank reached the position that it has determined to announce; but they do explain the *analysis* that justifies the position that has been reached. This analysis provides information about the bank's systematic approach to policy by illustrating its application to the concrete circumstances that have arisen since the last report; and it provides information about how conditions are likely to develop in the future through explicit discussion of the bank's own projections. Because the analysis is made public, it can be expected to shape future deliberations; the bank knows that it should be expected to explain why views expressed in the past are not later being followed. Thus, a commitment to transparency of this sort helps to make policy more fully rule-based, as well as increasing the public's understanding of the rule.

Another lesson is that *central banks must lead the markets*. Our statement above that it is not desirable for banks to surprise the markets might easily be misinterpreted to mean that central banks ought to try to do exactly what the markets expect, insofar as that can be determined. Indeed, the temptation to "follow the markets" becomes all the harder to avoid in a world where information about market expectations is easily available to central bankers as well as to the market participants themselves. But this would be a mistake, as Blinder (1998, chap. 3, sec. 3) emphasizes. If the central bank delivers whatever the markets expect, then there is no objective anchor for these expectations: Arbitrary changes in expectations may be *self-fulfilling* because the central bank validates them.[10] This would be destabilizing, for both nominal and real variables. To avoid this, central banks must take a stand as to the desired path of interest rates, and communicate it to the markets (as well as acting accordingly). While the judgments upon which such decisions are based will be fallible, failing to give a signal at all would be worse. A central bank should seek to minimize the extent to which the markets are surprised, but it should do this by conforming to a systematic rule of behavior and explaining it clearly, *not* by asking what others expect it to do.

This points up the fact that *policy should be rule-based.* If the bank does not follow a systematic rule, then no amount of effort at transparency will allow the public to understand and anticipate its policy. The question of the specific character of a desirable policy rule is also much too large a topic for the current occasion. However, a few remarks may be appropriate about what is meant by rule-based policy.

I do not mean that a bank should commit itself to an explicit state-contingent plan for the entire foreseeable future, specifying what it would do under every circumstance that might possibly arise. That would obviously be impractical, even under complete unanimity about the correct model of the economy and the objectives of policy, simply because of the vast number of possible futures. But it is not necessary in order to obtain the benefits of commitment to a systematic policy. It suffices that a central bank commit itself to a systematic way of determining an appropriate response to future developments, without having to list all of the implications of the rule for possible future developments.[11]

Nor is it necessary to imagine that commitment to a systematic rule means that once a rule is adopted it must be followed forever, regardless of subsequent improvements in understanding of the effects of monetary policy on the economy, including experience with the consequences of implementing the rule. If the private sector is forward-looking, and it is possible for the central bank to make the private sector aware of its policy commitments, then there *are* important advantages of commitment to a policy other than discretionary optimization—i.e., simply doing what seems best at each point in time, with no commitment regarding what may be done later. This is because there are advantages to having the private sector be able to anticipate *delayed* responses to a disturbance, that may not be optimal *ex post* if one re-optimizes taking the private sector's past reaction as given. But one can create the desired anticipations of subsequent behavior—and justify them—without committing to follow a fixed rule in the future no matter what may happen in the meantime.

It suffices that the private sector has no ground to forecast that the bank's behavior will be *systematically* different from the rule that it pretends to follow. This will be the case if the bank is committed to choosing a rule of conduct that is justifiable on certain *principles*, given its model of the economy.[12] The bank can then properly be expected to continue to follow its current rule, as long as its understanding of the economy does not change; and as long as there is no *predictable* direction in which its future model of the economy should be different from its current one, private-sector expectations should not be different from those in the case of an indefinite commitment to the current rule. Yet, changing to a better rule will remain possible in the case of improved knowledge (which is inevitable); and insofar as the change is justified both in terms of established principles and in terms of a change in the bank's model of the economy that can itself be defended, this need not impair the credibility of the bank's professed commitments.

It follows that rule-based policymaking will necessarily mean a decision process in which an explicit model of the economy (albeit one augmented by judgmental elements) plays a central role, both in the deliberations of the policy committee and in explanation of those deliberations to the public. This too has been a prominent feature of recent innovations in the conduct of monetary by the inflation-targeting central banks, such as the Bank of England, the Reserve Bank of New Zealand, and the Swedish Riksbank. While there is undoubtedly much room for improvement both in current models and current approaches to the use of models in policy deliberations, one can only expect the importance of models to policy deliberations to increase in the information economy.

Erosion of demand for the monetary base 2

Another frequently expressed concern about the effectiveness of monetary policy in the information economy has to do with the potential for erosion of private-sector demand for monetary liabilities of the central bank. The alarm has been raised, in particular, in a widely discussed recent essay by Benjamin Friedman (1999). Friedman begins by proposing that it is something of a puzzle that central banks are able to control the pace of spending in large economies by controlling the supply of "base money" when this monetary base is itself so small in value relative to the size of those economies. The scale of the transactions in securities markets through which central banks such as the U.S. Federal Reserve adjust the supply of base money is even more minuscule when compared to the overall volume of trade in those markets.[13]

He then argues that this disparity of scale has grown more extreme in the past quarter century as a result of institutional changes that have eroded the role of base money in transactions, and that advances in information technology are likely to carry those trends still farther in the next few decades.[14] In the absence of aggressive regulatory intervention to head off such developments, the central bank of the future will be "an army with only a signal corps"—able to indicate to the private sector how it believes that monetary conditions should develop, but not able to do anything about it if the private sector has opinions of its own. Mervyn King (1999) similarly proposes that central banks are likely to have much less influence in the twenty-first century than the did in the previous one, as the development of "electronic money" eliminates their monopoly position as suppliers of means of payment.

The information technology revolution clearly has the potential to fundamentally transform the means of payment in the coming century. But does this really threaten to eliminate the role of central banks as guarantors of price stability? Should new payments systems be regulated with a view to protecting central banks' monopoly position for as long as possible, sacrificing possible improvements in the efficiency of the financial system in the interest of macroeconomic stability?

I shall argue that these concerns as well are misplaced. Even if the more radical hopes of the enthusiasts of "electronic money" are realized, there is little reason to fear that central banks should not still retain the ability to control the level of overnight interest rates, and by so doing to regulate spending and pricing decisions in the economy in essentially the same way as at present. It is possible that the precise means used to implement a central bank's operating target for the overnight rate will need to change in order to remain effective in a future "cashless" economy, but the way in which these operating targets themselves are chosen in order to stabilize inflation and output may remain quite similar to current practice.

Will money disappear, and does it matter? *2.1*

There are a variety of reasons why improvements in information technology might be expected to reduce the demand for base money. Probably the most discussed of these—and the one of greatest potential significance for traditional measures of the monetary base—is the prospect that "smart cards" of various sorts might replace currency (notes and coins) as a means of payment in small, everyday transactions. In this case, the demand for currency issued by central banks might disappear. While experiments thus far have not made clear the degree of public acceptance of such a technology, many in the technology sector express confidence that "smart cards" should largely displace the use of currency within only a few years.[15] Others are more skeptical. Goodhart (2000), for example, argues that the popularity of currency will never wane—at least in the black-market transactions that arguably account for a large fraction of aggregate currency demand—owing to its distinctive advantages in allowing for unrecorded transactions. And improvements in information technology can conceivably make currency more attractive. For example, in the United States the spread of ATM machines has increased the size of the cash inventories that banks choose to hold, increasing currency demand relative to GDP.[16]

More to the point, in our view, is the observation that even a complete displacement of currency by "electronic cash" of one kind or another would in no way interfere with central-bank control of overnight interest rates. It is true that such a development could, in principle, result in a drastic reduction in the size of countries' monetary bases, since currency is, by far, the largest component of conventional measures of base money in most countries.[17] But neither the size nor even the stability of the overall demand for base money is of relevance to the implementation of monetary policy, unless central banks adopt monetary-base targeting as a policy rule—a proposal found in the academic literature,[18] but seldom attempted in practice.

What matters for the effectiveness of monetary policy is central-bank control of overnight interest rates,[19] and these are determined in the interbank market for the overnight central-bank balances that banks (or sometimes other financial institutions) hold in order to satisfy reserve requirements and to clear payments. The demand for currency affects this market only to the extent that banks obtain additional currency from the central bank in exchange for central-bank balances, as a result of which fluctuations in currency demand affect the supply of central-bank balances, to the extent that they are not accommodated by offsetting open-market operations by the central bank. In practice, central-bank operating procedures almost always involve an attempt to insulate the market for central-bank balances from these disturbances by automatically accommodating fluctuations in currency demand,[20] and this is one of the primary reasons that banks conduct open-market operations (though such operations are unrelated to any change in policy targets). Reduced use of currency, or even its total elimination, would only *simplify* the central bank's problem by eliminating this important source of disturbances to the supply of central-bank balances under current arrangements.

However, improvements in information technology may also reduce the demand for central-bank balances. In standard textbook accounts, this demand is due to banks' need to hold reserves in a certain proportion to transactions balances, owing to regulatory reserve requirements. However, faster information processing can allow banks to economize on required reserves, by shifting customers' balances more rapidly between reservable and non-reservable categories of accounts.[21] Indeed, since the introduction of "sweep accounts" in the United States in 1994, required reserves have fallen substantially.[22] At the same time, increased bank holdings of vault cash, as discussed previously, have reduced the need for Fed balances as a way of satisfying banks' reserve requirements. Due to these two developments, the demand for *Fed balances* to satisfy reserve requirements has become quite small—only a bit more than six billion dollars at present (see Table 1). As a consequence, some have argued that reserve requirements are already virtually irrelevant in the United States as a source of Fed control over the economy. Furthermore, the increased availability of opportunities for substitution away from deposits subject to reserve requirements predictably leads to further pressure for the reduction or even elimination of such regulations; as a result, recent years have seen a worldwide trend toward lower reserve requirements.[23]

But such developments need not pose any threat to central-bank control of overnight interest rates. A number of countries, such as the U.K., Sweden, Canada, Australia, and New Zealand, among others, have completed eliminated reserve requirements. Yet, these countries' central banks continue to implement monetary policy through operating targets for an overnight interest rate, and continue to have considerable success at achieving their operating targets. Indeed, as we show below, some of these central banks achieve tighter control of overnight interest rates than does the U.S. Federal Reserve.

The elimination of required reserves in these countries does not mean the disappearance of a market for overnight central-bank balances. Instead, central-bank balances are still used to clear inter-bank payments. Indeed, even in the United States, balances held to satisfy reserve requirements account for less than half of total Fed balances (as shown in Table 1),[24] and Furfine (2000) argues that variations in the demand for clearing balances account for the most notable high-frequency patterns the level and volatility of the funds rate in the United States. In the countries without reserve requirements, this demand for clearing purposes has simply become the sole source of demand for central-bank balances. Given the existence of a demand for clearing balances (and, indeed, a somewhat interest-elastic demand, as discussed in the next section), a central bank can still control the overnight rate through its control of the net supply of central-bank balances.

Nonetheless, the disappearance of a demand for required reserves may have consequences for the way that a central bank can most effectively control overnight interest rates. In an economy with an efficient interbank market, the aggregate demand for clearing balances will be quite small relative to the total volume of payments in the economy; for example, in the United States, banks that actively participate in the payments system typically send and receive payments each day about

Table 1
Reserves and Balances[1]

Required reserves	
Applied vault cash	32.3
Fed balances to satisfy reserve requirements	6.5
Total required reserves	38.8
Fed balances	
Required clearing balances	7.1
Adjustment to compensate for float	.4
Fed balances to satisfy reserve requirements	6.5
Excess reserves	1.1
Total Fed balances	15.1

[1] Reserves held to satisfy legal reserve requirements, and total balances of depository institutions held with U.S. Federal Reserve Banks. Averages for the two-week period ending August 8, 2001, in billions of dollars.
Sources: Federal Reserve Statistical Release H.3, August 9, 2001, and Statistical Release H.4.1, August 2, 2001, and August 9, 2001.

thirty times the size of their average overnight clearing balances, and the ratio is as high as 200 for the most active banks (Furfine, 2000). Exactly for this reason, random variation in daily payments flows can easily lead to fluctuations in the net supply of and demand for overnight balances that are large relative to the average level of such balances.[25] This instability is illustrated by Chart 2, showing the daily variation in aggregate overnight balances at the Reserve Bank of Australia, over several periods during which the target overnight rate does not change, and over which the actual overnight rate is also relatively stable (as shown in Chart 1).

A consequence of this volatility is that quantity targeting—say, adoption of a target for aggregate overnight clearing balances, while allowing overnight interest rates to attain whatever level should clear the market, as under the nonborrowed reserves targeting procedure followed in the United States in the period 1979-1982—will not be a reliable approach to stabilization of the aggregate volume of spending, if practicable at all. And even in the case of an operating target for the overnight interest rate, the target is not likely to be most reliably attained through daily open-market operations to adjust the aggregate supply of central-bank balances, the method currently used by the Fed. The overnight rate at which the interbank market clears is likely to be highly volatile, if the central bank conducts an open-market operation only once, early in the day, and there are no standing facilities of the kind that limit variation of the overnight rate under the "channel" systems discussed below. In the United States at present, errors in judging the size of the open-market operation required on a given day can be corrected only the next day without this resulting in daily fluctuations in the funds rate that are too great, owing to the intertemporal substitution in the demand for Fed balances stressed by Taylor (2001). But the scope for intertemporal substitution results largely from the fact that U.S. reserve requirements apply only to average reserves over a two-week period; and, indeed, funds rate volatility is observed to be higher on the last day of a reserve maintenance period (Spindt and Hoffmeister, 1988; Hamilton, 1996; Furfine, 2000). There is no similar reason for intertemporal substitution in the demand for clearing balances, as penalties for overnight overdrafts are imposed on a daily basis.[26] Hence, the volatility of the overnight interest rate, at least at the daily frequency, could easily be higher under such an operating procedure, in the complete absence of (or irrelevance of) reserve requirements.[27]

Many central banks in countries that no longer have reserve requirements, nonetheless, achieve tight control of overnight interest rates, through the use of a "channel" system of the kind described in the next section. In a system of this kind, the overnight interest rate is kept near the central bank's target rate through the provision of standing facilities by the central bank, with interest rates determined by the target rate. Such a system is likely to be more effective in an economy without reserve requirements, and one may well see a migration of other countries, such as the United States, toward such a system as existing trends further erode the role of legal reserve requirements.

Improvements in information technology may well reduce the demand for central-bank balances for clearing purposes as well. As the model presented below shows, the demand for non-zero overnight clearing balances results from uncertainty about banks' end-of-day positions in their clearing accounts that has not yet been resolved at the time of trading in the interbank market. But such uncertainty is entirely a function of imperfect communication; were banks to have better information sooner about their payment flows, and were the interbank market more efficient at allowing trading after the information about these flows has been fully revealed, aggregate demand for overnight clearing balances would be smaller and less interest-elastic. In principle, sufficiently accurate monitoring of payments flows should allow each bank to operate with zero overnight central-bank balances.

Yet, once again, I would argue that future improvements in the efficiency of the financial system pose no real threat to central-bank control of overnight rates. The model presented implies that the effects upon the demand for clearing balances of reduced uncertainty about banks' end-of-day positions can be offset by reducing the opportunity cost of overnight balances as well, by increasing the rate of interest paid by the central bank on such balances. In order for the interbank market to remain active, it is necessary that the interest paid on overnight balances at the central bank not be made as high as the target for the market overnight rate. But as the interbank market becomes ever more frictionless (the hypothesis under consideration), the size of the spread required for this purpose becomes smaller. There should always be a range of spreads that are small enough to make the demand for clearing balances interest-elastic, while, nonetheless, large enough to imply that banks with excess balances will prefer to lend these in the interbank market, unless the overnight rate in the interbank market is near the deposit rate, and, thus, well below the target rate. (This latter behavior is exactly what is involved in an interest-elastic demand for overnight balances.) Thus, once again, some modification of current operating procedures may be required, but without any fundamental change in the way that central banks can affect overnight rates.

Finally, some, such as Mervyn King (2000), foresee a future in which electronic means of payment come to substitute for current systems in which payments are cleared through central banks.[28] This prospect is highly speculative at present; most current proposals for variants of "electronic money" still depend upon the final settlement of transactions through the central bank, even if payments are made using electronic signals rather than old-fashioned instruments such as paper checks. And Charles Freedman (2000), for one, argues that the special role of central banks in providing for final settlement is unlikely ever to be replaced, owing to the unimpeachable solvency of these institutions, as government entities that can create money at will. Yet, the idea is conceivable, at least in principle, since the question of finality of settlement is ultimately a question of the quality of one's information about the accounts of the parties with whom one transacts—and while the development of central banking has undoubtedly been a useful way of economizing on limited information-processing capacities, it is not clear that advances in information technology could not make other methods viable.

One way in which the development of alternative, electronic payments systems might be expected to constrain central bank control of interest rates is by limiting the ability of a central bank to raise overnight interest rates when this might be needed to restrain spending and, hence, upward pressure on prices. Here, the argument would be that high interest rates might have to be avoided in order not to raise too much the opportunity cost of using central-bank money, giving private parties an incentive to switch to an alternative payments system. But such a concern depends upon the assumption, standard in textbook treatments of monetary economics, that the rate of interest on money must be zero, so that "tightening" policy always means raising the opportunity cost of using central-bank money. Under such an account, effective monetary policy depends upon the existence of central-bank monopoly power in the supply of payments services, so that the price of its product can be raised at will through sufficient rationing of supply.

Yet, raising interest rates in no way requires an increase in the opportunity cost of central-bank clearing balances, for one can easily pay interest on these balances, and the interest rate paid on overnight balances can be raised in tandem with the increase in the target overnight rate. This is exactly what is done under the "channel" systems described below. Of course, there is a "technological" reason why it is difficult to pay an interest rate other than zero on currency.[29] But this would not be necessary in order to preserve the central bank's control of overnight interest rates. As noted above, the replacement of currency by other means of payment would pose no problem for monetary control at all. (Highly interest-elastic currency demand would complicate the implementation of monetary policy, as large open-market operations might be needed to accommodate the variations in currency demand. But this would not undermine or even destabilize the demand for central-bank balances.) In order to prevent a competitive threat to the central-bank-managed clearing system, it should suffice that the opportunity cost of holding overnight clearing balances be kept low. The evident network externalities associated with the choice of a payments system, together with the natural advantages of central banks in performing this function stressed by Freedman (2000), should then make it likely that many payments would continue to be settled using central-bank accounts.

My conclusion is that while advances in information technology may well require changes in the way in which monetary policy is implemented in countries like the United States, the ability of central banks to control inflation will not be undermined by advances in information technology. And in the case of countries such as Canada, Australia, or New Zealand, the method of interest-rate control that is currently used—the "channel" system described below—should continue to be quite effective, even in the face of the most radical of the developments that are currently envisioned. I turn now to a further consideration of the functioning of such a system.

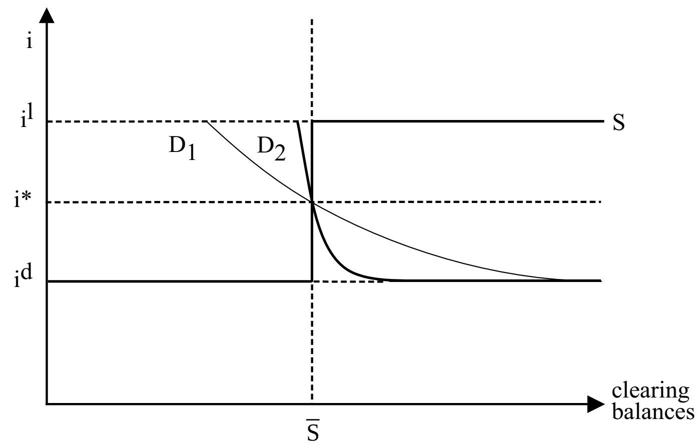
Interest-rate control using standing facilities 2.2

The basic mechanism through which the overnight interest rate in the interbank market is determined under a "channel" system can be explained using Figure 1.[30] The model sketched here is intended to describe determination of the overnight interest rate in a system such as that of Canada, Australia, or New Zealand, where there are no reserve requirements.[31] Under such a system, the central bank chooses a target overnight interest rate (indicated by i^* in the figure), which is periodically adjusted in response to changing economic conditions.[32]

In addition to supplying a certain aggregate quantity of clearing balances (which can be adjusted through open-market operations), the central bank offers a lending facility, through which it stands ready to supply an arbitrary amount of additional overnight balances at a fixed interest rate. The lending rate is indicated by the level i^l in Figure 1. In Canada, Australia, and New Zealand, this lending rate is generally set exactly 25 basis points higher than the target rate.[33] Thus, there is intended to be a small penalty associated with the use of this lending facility rather than acquiring funds through the interbank market. But funds are freely available at this facility (upon presentation of suitable collateral), without the sort of rationing or implicit penalties associated with discount-window borrowing in the United States.[34]

Finally, depository institutions that settle payments through the central bank also have the right to maintain excess clearing balances overnight with the central bank at a deposit rate. This rate is indicated by i^d in Figure 1. The deposit rate is positive but slightly lower than the target overnight rate, again so as to penalize banks slightly for not using the interbank market. Typically, the target rate is the exact center of the band whose upper and lower bounds are set by the lending rate and the deposit rate. Thus, in the countries just mentioned, the deposit rate is generally set exactly 25 basis points below the target rate.[35] The lending rate, on the one hand, and the deposit rate on the other then define a channel within which overnight interest rates should be contained.[36] Because these are both standing facilities, no bank has any reason to pay another bank a higher rate for overnight cash than the rate at which it could borrow from the central bank; similarly, no bank has any reason to lend overnight cash at a rate lower than the rate at which it can deposit with the central bank. Furthermore, the spread between the lending rate and the deposit rate

Figure 1
Supply and Demand for Clearing Balances under a "Channel" System



give banks an incentive to trade with one another (with banks that find themselves with excess clearing balances lending them to those that find themselves short) rather than depositing excess funds with the central bank when long and borrowing from the lending facility when short. The result is that the central bank can control overnight interest rates within a fairly tight range regardless of what the aggregate supply of clearing balances may be; frequent quantity adjustments accordingly become less important.

Overnight rate determination under such a system can be explained fairly simply. The two standing facilities result in an effective supply curve for clearing balances of the form indicated by schedule S in Figure 1. The vertical segment is located at $\bar{S}$, the net supply of clearing balances apart from any obtained through the lending facility. This is affected by government payments and variations in the currency demands of banks, in addition to the open-market operations of the central bank. Under a channel system, the central bank's target supply of clearing balances may vary from day to day, but it is adjusted for technical reasons (for example, the expectation of large payments on a particular day) rather than as a way of implementing or signaling changes in the target overnight rate (as in the United States). The horizontal segment to the right at the lending rate indicates the perfectly elastic supply of additional overnight balances from the lending facility. The horizontal segment to the left at the deposit rate indicates that the payment of interest on deposits puts a floor on how low the equilibrium overnight rate can fall, no matter how low the demand for clearing balances may be. The equilibrium overnight rate is then determined by the intersection of this schedule with a demand schedule for clearing balances, such as the curve D1 in the figure.[37]

A simple model of the determinants of the demand for clearing balances can be derived as follows.[38] To simplify, we shall treat the interbank market as a perfectly competitive market, held at a certain point in time, that occurs after the central bank's last open-market operation of the day, but before the banks are able to determine their end-of-day clearing balances with certainty. The existence of residual uncertainty at the time of trading in the interbank market is crucial;[39] it means that even after banks trade in the interbank market, they will expect to be short of funds at the end of the day with a certain probability, and also to have excess balances with a certain probability.[40] Trading in the interbank market then occurs to the point where the risks of these two types are just balanced for each bank.

Let the random variable z^i denote the net payments to bank i during a given day; that is, these represent the net additions to its clearing account at the central bank by the end of the day. At the time of trading in the interbank market, the value of z^i is not yet known with certainty, although a good bit of the uncertainty will have been resolved. Let $\varepsilon^i \equiv z^i - E(z^i)$ represent the eventual end-of-day surprise; here and below $E(\cdot)$ denotes an expectation conditional upon information at the time of trading in the interbank market. Let us suppose furthermore that the random variable ε^i/σ^i has a distribution with cdf F for each bank; here, $\sigma^i > 0$ is a parameter (possibly different from day to day, for reasons of the sort discussed by Furfine, 2000) that indexes the degree of uncertainty of bank i. Because of this uncertainty, a bank that trades in the interbank market to the point where its expected end-of-day balance (at the time of trading) is s^i will have an actual end-of-day balance equal to $s^i + \varepsilon^i$. It is convenient to use s^i as the bank's choice variable in modeling its trading in the interbank market.

A risk-neutral bank should then choose s^i in order to maximize expected returns $E(R)$, where its net return R on its overnight balances at the central bank is equal to

$$R(s^i,\varepsilon^i) = i^d \max(s^i + \varepsilon^i, 0) + i^l \min(s^i + \varepsilon^i, 0) - is^i, \quad (2.1)$$

if i is the rate at which overnight funds can be lent or borrowed in the interbank market. Note that the bank's net lending in the interbank market is equal to its beginning-of-day balances plus $E(z^i) - s^i$; this differs by a constant (i.e., a quantity that is independent of the bank's trading decision) from the quantity $-s^i$ that enters expression (2.1). If the cdf F is continuous, the first-order condition for optimal choice of s^i is then given by

$$(i^d - i)(1 - F(-s^i / \sigma^i)) + (i^l - i)F(-s^i / \sigma^i) = 0,$$

implying desired overnight balances of

$$s^i = -\sigma^i F^{-1}\left(\frac{i - i^d}{i^l - i^d}\right). \quad (2.2)$$

Aggregating over banks i, we obtain the demand schedule plotted in Figure 1. As one would expect, the demand schedule is decreasing in i. In the figure, desired balances are shown as becoming quite large as i approaches i^d ; this reflects assignment of a small but positive probability to the possibility of very large negative payments late in the day, which risk banks will wish to insure against if the opportunity cost of holding funds overnight with the central bank is low enough.

The market-clearing overnight rate i is then the rate that results in an aggregate demand such that

$$\sum_i s^i = \bar{S} + u, \quad (2.3)$$

Here, the net supply of clearing balances expected at the time of trading in the interbank market[41] is equal to the central bank's target supply of clearing balances $\bar{S}$, plus a random term u. The latter term represents variation in the aggregate supply of clearing balances (due to currency demand by banks or government payments, for example) that has not been correctly anticipated by the central bank at the time of its last open-market operation (and so offset), but that has been revealed by the time of trading in the interbank market.[42] The quantity $\bar{S}+u$ represents the location on the horizontal axis of the vertical segment of the effective supply schedule in Figure 1. (The figure depicts equilibrium in the case that $u=0$.)

Substitution of (2.2) into (2.3) yields the solution

$$i = i^d + F\left(-\frac{\bar{S}+u}{\sum_i \sigma^i}\right)(i^l - i^d). \tag{2.4}$$

As noted above, the market overnight rate is necessarily within the channel: $i^d \leq i \leq i^l$. Its exact position within the channel will be a decreasing function of the supply of central-bank balances $\bar{S}+u$. It is important to note that the interest rates associated with the two standing facilities play a crucial role in determining the equilibrium overnight rate, even if the market rate *remains always in the interior of the channel* (as is typical in practice, and as is predicted by the model if the support of ε^i/σ^i is sufficiently wide relative to the support of u). This is because these rates matter not only for the determination of the location of the horizontal segments of the effective supply schedule S, but also for the location of the demand schedule D. Alternatively, the locations of the standing facilities matter because individual banks do resort to them with positive probability, even though it is not intended that the overnight rate should ever be driven to either boundary of the channel.

The model predicts an equilibrium overnight rate at the target rate (the midpoint of the channel),

$$i = i^* = \frac{i^d + i^l}{2},$$

when $u = 0$ (variations in the supply of clearing balances are successfully forecasted and offset by the central bank) and the target supply of clearing balances is equal to

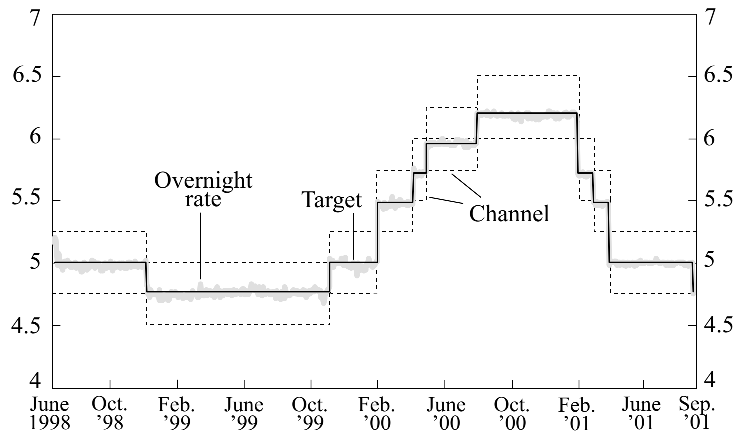
$$\bar{S} = -F^{-1}(1/2)\sum_i \sigma^i. \tag{2.5}$$

As long as the central bank is sufficiently accurate in estimating the required supply of clearing balances (2.5) and in eliminating the variations represented by the term u; the equilibrium fluctuations in the overnight rate around this value should be small (and it should be near the target rate on average).

In the case of a symmetric distribution for ε^i (or any distribution such that zero is the median as well as the mean), (2.5) implies that the required target supply of clearing balances should be *zero*. In practice, it seems that a small positive level of aggregate clearing balances are typically desired when the overnight rate remains in the center of the channel,[43] indicating some asymmetry in the perceived risks.[44] Thus, a small positive target level of clearing balances is appropriate; but the model explains why this can be quite small.

The more important prediction of the model, however, is that the demand for clearing balances should be a function of the location of the overnight rate *relative* to the lending rate and deposit rate, but independent of the *absolute level* of any of these interest rates.[45] This means that an adjustment of the level of overnight rates by the central bank need not require any change in the supply of clearing balances, as long as the location of the lending and deposit rates relative to the target overnight rate do not change. Thus, under a channel system, changes in the level of overnight interest rates are brought about by simply announcing a change in the target rate, which has the implication of changing the lending and deposit rates at the central bank's standing facilities; no quantity adjustments in target supply of clearing balances are required.

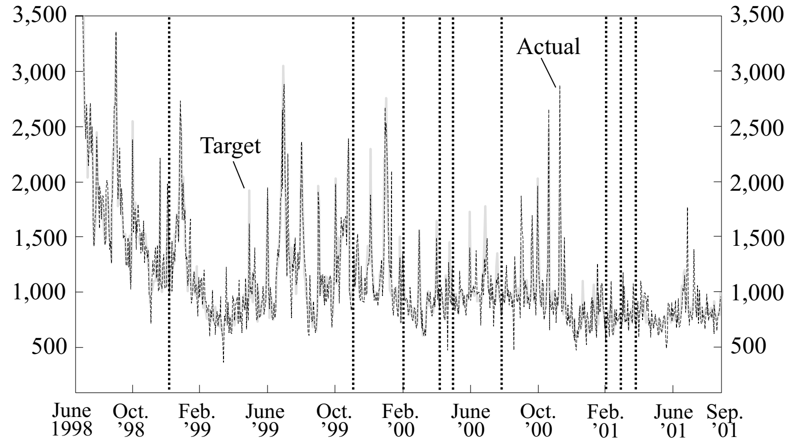
Chart 1
The Overnight Rate since the Introduction of the RTGS System in Australia



Open-market operations (or their equivalent) are still used under such a system.[46] But rather than being used either to signal or to enforce a change in the operating target for overnight rates, as in the United States, these are a purely technical response to daily changes in the Bank’s forecast of external disturbances to the supply of clearing balances, and to its forecast of changes in the degree of uncertainty regarding payment flows. The bank acts each day in order to keep $(S + u)/\Sigma_i\sigma^i$ as close as possible to its desired value,[47] which desired value is independent of both the current operating target i^* and the rate i at which the interbank market might currently be trading, unlike the reaction function of the Trading Desk of the New York Fed described by Taylor (2001).[48]

The degree to which the system succeeds in practice in Australia is shown in Chart 1, which plots the overnight interest rate in since adoption of the complete system described here in June 1998.[49] The channel established by the RBA’s standing facilities is plotted as well. One observes that the overnight interest rate not only remains well within

Chart 2
Total Daily ES Account Balances in Australia

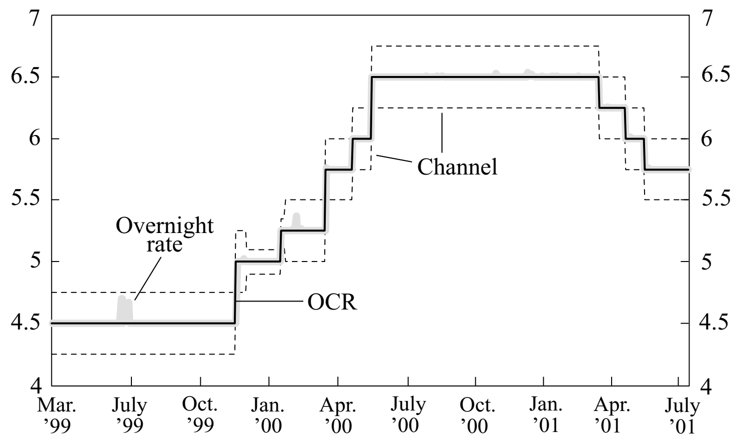


Note: Dotted vertical lines mark the dates of target overnight rate changes.

the channel at all times, but that on most days it remains quite close to the target rate (the center of the channel).

On the dates at which the target rate is adjusted (by 25 or 50 basis points at a time), the overnight rate immediately jumps to within a few basis points of the new target level. Furthermore, these changes in the overnight rate do not require adjustments of the supply of clearing balances. Both the RBA's target level[50] of clearing balances (ES balances) and actual overnight balances are plotted in Chart 2. Here, the vertical dotted lines indicate the dates of the target changes shown in Chart 1. While there are notable day-to-day variations in both target and actual balances, these are not systematically lower when the Bank aims at a higher level of overnight rates. Thus, the ability of the RBA to "tighten" policy is in no way dependent upon the creation of a greater "scarcity" of central-bank balances. This is a direct consequence of the fact that interest rates are raised under this system without any attempt to change the spread between market rates of return

Chart 3
The Overnight Rate under the OCR System in New Zealand



and the interest paid on bank reserves. Instead, the target supply of clearing balances is frequently adjusted for technical reasons at times unrelated to policy changes. For example, target balances were more than doubled during the days spanning the "Y2K" date change, as a result of increased uncertainty about currency demand, though this was not associated with any change in the bank's interest-rate target, and only modest variation in actual overnight rates.[51]

A similar system has proven even more strikingly effective in New Zealand, where it was also adopted at the time of the introduction of an RTGS payment system, in March 1999.[52] Chart 3 provides a similar plot of actual and target rates, as well as the rates associated with the standing facilities, in New Zealand under the OCR system. On most days, the actual overnight rate is equal to the OCR, to the nearest basis point, so that the dotted line indicating the OCR is not visible in the figure. Changes in the OCR bring about exactly the same change in the actual overnight rate, and these occur without any change in the RBNZ's "settlement cash target," which is held fixed (at

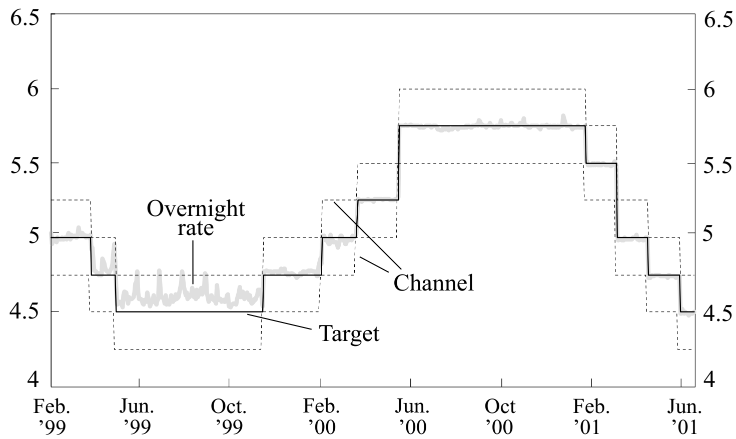
$20 million NZ) during this period, except for an increase (to $200 million NZ) for a few weeks around the "Y2K" date change (Hampton, 2000).

The accuracy with which the RBNZ achieves its target for overnight rates (except for occasional deviations that seldom last more than a day or two) may seem too perfect to be believed. This indicates that the interbank market in New Zealand is not an idealized auction market of the kind assumed in our simple model. Instead, the banks participating in this market maintain a convention of trading with one another at the OCR, except for infrequent occasions when the temptation to deviate from this norm is evidently too great[53] The appeal of such a convention under ordinary circumstances is fairly obvious. When the target rate is at the center of the channel, trading at the target rate implies an *equal division* of the gains from trade. This may well seem fair to both parties, and agreeing to the convention has the advantage of allowing both to avoid the costs of searching for alternative trading partners or of waiting for further information about that day's payment flows to be revealed.

If the central bank is reasonably accurate in choosing the size of its daily open-market operation, the Walrasian equilibrium overnight rate (modeled above) is never very far from the center of the channel in any event, and so no one may perceive much gain from insisting upon more competitive bidding. Occasional breakdowns of the convention occur on days when the RBNZ is unable to prevent a large value of u from occurring, for example on days of unusually large government payments; on such days, the degree to which the convention requires asymmetries in bargaining positions to be neglected is too great for all banks to conform. Thus, even in the presence of such a convention, our simple model is of some value in explaining the conduct of policy under a channel system. For preservation of the convention depends upon the central bank's arranging things so that the rate that *would* represent a Walrasian equilibrium, if such an idealized auction were conducted, is not too far from the center of the channel.

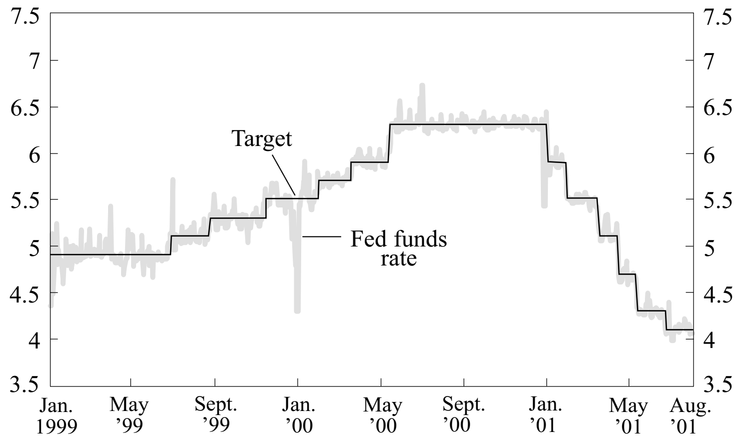
Chart 4 similarly plots the overnight rate in Canada since the adop-

Chart 4
The Overnight Rate since Introduction of the LVTS System in Canada



tion of the LVTS (Large-Value Transfer System) clearing system in February 1999.[54] Once again, one observes that the channel system has been quite effective, at least since early in 2000, at keeping the overnight interest rate not only within the Bank's 50-basis-point "operating band" but usually within about one basis point of the target rate. In the early months of the Canadian system, it is true, the overnight rate was chronically higher than the target rate, and even above the upper bound of the operating band (the Bank Rate) at times of particular liquidity demand.[55] This was due to an underestimate of the supply of clearing balances $\bar{S}$ needed for the market to clear near the center of the channel. The Bank of Canada had originally thought that a zero net supply of clearing balances was appropriate (see, e.g., Clinton, 1997), but by late in 1999 began instead to target a positive supply, typically $200 million Canadian, as noted above. This, together with some care to adjust of the supply of settlement balances from day to day in response to variation in the volume of payments, has resulted in much more successful control of the overnight rate.

Chart 5
The U.S. Fed Funds Rate and the Fed's Operating Target



All three of these countries now achieve considerably tighter control of overnight interest rates in their countries than is achieved, for example, under the current operating procedures employed in the United States. For purposes of comparison, Chart 5 plots the federal funds rate (the corresponding overnight rate for the United States) since the beginning of 1999, together with the Fed's operating target for the funds rate. It is evident that the daily deviations from the target rate are larger in the United States.[56] Nor can this difference easily be attributed to differences in the size or structure of the respective economies' banking systems; for in the first half of the 1990s, both Canada and New Zealand generally had *more volatile* overnight interest rates than did the United States (Sellon and Weiner, 1997, chart 3).

An especially telling comparison regards the way the different systems were able to deal with the strains created by the increase in uncertainty about currency demand at the time of the "Y2K" panic. In the United States, where variations in the supply of Fed balances is the only tool used to control overnight rates, the Fed's large year-end open-market operations in response to increased currency demand may have been perceived as implying a desire to reduce the funds rate; in any event, it temporarily traded more than 150 basis points below the Fed's operating target (Taylor, 2001). Subsequent open-market operations to withdraw the added cash also resulted in a funds rate well above target weeks after the date change. In New Zealand, large open-market operations were also conducted, and in addition to accommodating banks' demand for currency, the RBNZ's "settlement cash target" was increased by a factor of 10. But the use of a channel system—with the width of the channel substantially narrowed, to only 20 basis points—continued to allow tight control of the overnight rate, which never deviated at all from the target rate (to the nearest basis point) during this period (Hampton, 2000). Similarly, in Canada the overnight money market financing rate never deviated by more than 1 or 2 basis points from the Bank of Canada's target rate in the days surrounding the change of millennium. In Australia, the cash rate fell to as much as 6 or 7 basis points below target on some days in the week before and after the date change, but the deterioration of interest-rate control was still small and short-lived.[57]

Given a channel system for the implementation of monetary policy, like that currently used in Canada, Australia, and New Zealand, there is little reason to fear that improvements in information technology should undermine the effectiveness of central-bank control of overnight interest rates. Neither the erosion of reserve requirements nor improvements in the ability of banks to closely manage their clearing balances should pose particular difficulties for such a system, for these are exactly the developments that led to the introduction of channel systems in the countries mentioned, and the systems have, thus far, worked quite well.

Both the elimination of reserve requirements and increases in the efficiency with which clearing balances can be tracked should be expected not only to reduce the quantitative magnitude of the net demand for overnight central-bank balances, but also to render this demand less interest sensitive. We have discussed above the way in which the presence of effective reserve requirements (averaged over a maintenance period) makes the daily demand for central-bank balances more interest sensitive, by increasing the intertemporal substitutability of such demand. The effect of increased ability of banks to accurately estimate their end-of-day clearing balances can be easily seen with the help of the model just sketched; reduction of σ^i for each of the banks shifts the demand schedule obtained by summing (2.2) from one like D_1 in Figure 1 to one more like D_2. In either case, the reduction in the interest sensitivity of the demand for central-bank balances increases the risk of volatility of the overnight rate owing to errors in the central bank's estimate of the size of open-market operation required on a given day to fulfill that day's demand for overnight balances at the target interest rate, rendering quantity adjustments less effective as a means of enforcing a bank's interest-rate target. It is, thus, not surprising that in all three of the countries discussed, the channel systems described above were introduced at the time of the introduction of new, more efficient clearing systems.[58]

Under such a system, further improvements in the efficiency of the payments system, tending to render the demand for overnight balances even less responsive to interest-rate changes, can be offset by a further narrowing of the width of the channel. Note that (2.2) implies that the slope of the demand schedule in Figure 1, evaluated near the target interest rate (midpoint of the channel), is equal to

$$\frac{dD}{di} = -\frac{\sum_i \sigma^i}{(i^l - i^d) f(\mu)},$$

where μ is the median value of ε^i/σ^i and $f(\mu) \equiv F'(\mu)$ is the probability density function at that point. Thus, interest-sensitivity is reduced by reductions in uncertainty about banks' end-of-day positions, as noted, but any such change can be offset by a suitable narrowing of the width of the channel $i^l - i^d$, so that the effect upon the equilibrium overnight rate (in basis points) of a given size error in the size of the required open-market operation on a particular day (in dollars) would remain unchanged. Since the main reason for not choosing too narrow a channel—concern that a sufficient incentive remain for the reallocation of clearing balances among banks through the interbank market (Brookes and Hampton, 2000)—becomes less of a concern under the hypothesis of improved forecastability of end-of-day positions, a narrower channel would seem quite a plausible response.

Nor should a channel system be much affected by the possible development of novel media for payments. The replacement of currency by "smart cards" would only simplify day-to-day central bank control of the supply of clearing balances, ensuring that the target $\bar{S}$ would be maintained more reliably. And the creation of alternative payments networks would probably not result in complete abandonment of the central bank's system for purposes of final settlement, as long as the costs of using that system can be kept low. Under a channel system, the opportunity cost of maintaining clearing balances with the central bank is equal only to $i^l - i^d$ or (assuming an equilibrium typically near the midpoint of the channel) only half the width of the channel. This cost is small under current conditions (25 basis points annually, in the countries under discussion), but might well be made smaller if improvements in information processing further increase the accuracy of banks' monitoring of their clearing balances.

The development of alternative payments systems is likely to lead to increasing pressure from financial institutions for reduction in the cost of clearing payments through the central bank, both through reduction of reserve requirements and through payment of interest on central-bank balances. And the reduction of such taxes on the use of central-bank money can be defended on public-finance grounds even under current conditions.[59] From this point of view as well, the channel systems of Canada, Australia, and New Zealand may well represent the future of payment systems worldwide.

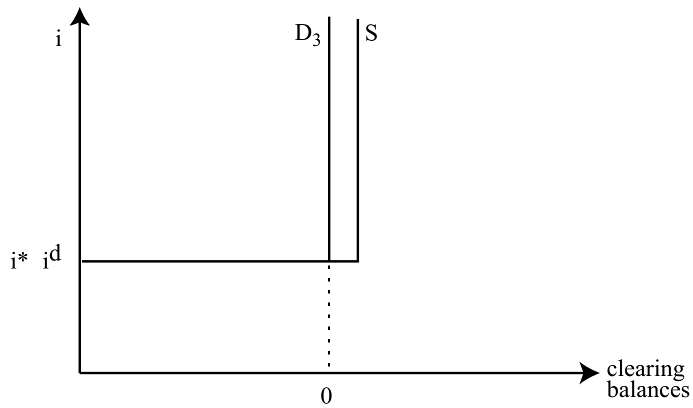
It is worth noting, however, that a consideration of the usefulness of a channel system for monetary control leads to a somewhat different perspective on the payment of interest on reserves than is often found in discussions of that issue from the point of view solely of tax policy. For example, it is sometimes proposed that it might be sufficient to pay interest on *required* reserves only, rather than on total central-bank balances, on the grounds that a tax that cannot be avoided (or can be avoided only by reducing the scale of one's operations) is an especially onerous one. But if there continues to be zero interest on "excess reserves," then the interest rate on *marginal* central-bank balances continues not to be adjusted with changes in the target level of overnight rates, and it continues to be the case that changes in the overnight rate must be brought about through changes in the degree to which the supply of central-bank balances is rationed.

Similarly, it is often supposed that the interest that should be paid on reserves on efficiency grounds should be a rate that is tied to market interest rates. This may seem to follow immediately from the fact that the spread $i - i^d$ is analogous to a tax on holding balances overnight with the central bank; fixing i^d to equal i minus a constant spread would then be a way of keeping this tax rate constant over time. But raising the deposit rate automatically with increases in the overnight rate means that such increases will no longer increase the opportunity cost of holding overnight balances; this will make the demand for overnight balances much less interest-sensitive, and so make control of the overnight rate by the central bank more difficult, if not impossible.[60] Tying the deposit rate to the *target* overnight rate, as in the channel systems just described, instead helps to keep the market rate near the target rate. In *equilibrium*, the spread between the market overnight rate and the deposit rate should thereby be kept from varying much, so that the goal of a fairly constant effective tax rate is also achieved. But with this approach to the problem of reducing the cost of holding overnight balances, the twin goals of microeconomic efficiency and macroeconomic stability can both be served.

Interest-rate control in the absence of monetary frictions 3

I have argued that there is little reason to fear that improvements in information technology should threaten the ability of central banks to control overnight interest rates, and, hence, to pursue their stabilization goals in much the way they do at present; indeed, increased opportunity to influence market expectations should make it possible for monetary policy to be even more effective. There is nothing to fear from increased efficiency of information transmission in markets,

Figure 2
The Interbank Market When Central-Bank Balances Are No Longer Used for Clearing Purposes



because the effectiveness of monetary policy depends neither upon fooling market participants nor upon the manipulation of market distortions that depend upon monopoly power on the part of the central bank.

Some will doubtless wonder if this can really be true. They may feel that such an optimistic view fails to address the puzzle upon which Friedman (1999) remarks: If banks have no special powers at their disposal, how can it be that such small trades by central banks can move rates in such large markets? In the complete absence of any monopoly power on the part of central banks—because their liabilities no longer supply any services not also supplied by other equally riskless, equally liquid financial claims—it might be thought that any remaining ability of central banks to affect market rates would have to depend upon a capacity to adjust their balance sheets by amounts that are large relative to the overall size of financial markets.

Of course, one might still propose that central banks should be able to engage in trades of any size that turned out to be required, owing to the fact that the government stands behind the central bank and can use its power of taxation to make up any trading losses, even huge ones.[61] But I shall argue instead that massive adjustments of central-bank balance sheets would not be necessary in order to move interest rates, even in a world where central-bank liabilities ceased to supply any services in addition to their pecuniary yield. Thus, the claim that banks should still be as effective at pursuing their stabilization objectives in a world with informationally efficient financial markets does not depend upon a supposition that central banks ought to be willing to trade on a much more ambitious scale than they do at present.

The source of central-bank control of short-term interest rates 3.1

In our discussion above, we have supposed that even in the future there would continue to be some small demand for central-bank balances (if only for clearing purposes) at a positive opportunity cost. But the logic of the method of interest-rate control sketched above does not really depend upon this. Let us suppose instead that balances held with the central bank cease to be any more useful to commercial banks than any other equally riskless overnight investment. In this case, the demand for central-bank balances would collapse to a vertical line at zero for all interest rates higher than the settlement cash rate, as shown in Chart 5, together with a horizontal line to the right at the settlement cash rate. That is, banks should still be willing to hold arbitrary balances at the central bank, as long as (but only if) the overnight cash rate is no higher than the rate paid by the central bank. In this case, it would no longer be possible to induce the overnight cash market to clear at a target rate. higher than the rate paid on settlement balances.

But the central bank could still control the equilibrium overnight rate, by choosing a positive settlement cash target, so that the only possible equilibrium would be at an interest rate equal to the settlement cash rate, as shown in Chart 5. Such a system would differ from current channel systems in that an overnight lending facility would no longer be necessary, so that there would no longer be a “channel.”[62] And the rate paid on central-bank balances would no longer be set at a fixed spread below the target overnight rate; instead, it would be set at exactly the target rate. But perfect control of overnight rates should still be possible through adjustments of the rate paid on overnight central-bank balances,[63, 64] and changes in the target overnight rate would not have to involve any change in the settlement cash target, just as is true under current channel systems. Indeed, in this limiting case, variations in the supply of central-bank balances would cease to have any effect at all upon the equilibrium overnight rate. Thus, it would be essential to move from a system like that of the United States a present—in which variations in the supply of Fed balances is the *only* tool used to affect the overnight rate, while the interest rate paid on these balances is never varied at all [65]—to one in which instead variations in overnight rates are achieved purely through variations in the rate paid on Fed balances, and not at all through supply variations.

How can interest-rate variation be achieved without any adjustment at all of the supply of central-bank balances? Certainly, if a government decides to peg the price of some commodity, it may be able to do so, but only by holding stocks of the commodity that are sufficiently large relative to the world market for that commodity, and by standing ready to vary its holdings of the commodity by large amounts as necessary. What is different about controlling short-term nominal interest rates?

The difference is that there is no inherent "equilibrium" level of interest rates to which the market would tend in the absence of central-bank intervention, and against which the central bank must, therefore, exert a significant countervailing force in order to achieve a given operating target.[66] This is because there is no inherent value (in terms of real goods and services) for a fiat unit of account such as the "dollar," except insofar as a particular exchange value results from the monetary policy commitments of the central bank.[67] Alternative price-level paths are, thus, equally consistent with market equilibrium in the absence of any intervention that would vary the supply of any real goods or services to the private sector. And associated with these alternative paths for the general level of prices are alternative paths for short-term nominal interest rates.

Of course, this analysis might suggest that while central banks can bring about an arbitrary level of *nominal* interest rates (by creating expectations of the appropriate rate of inflation), they should not be able to significantly affect *real* interest rates, except through trades that are large relative to the economy that they seek to affect. It may also suggest that banks should be able to move nominal rates only by altering inflation expectations; yet, banks generally do not feel that they can easily alter expectations of inflation over the near term, so that one might doubt that banks should be able to affect *short-term* nominal rates through such a mechanism.

However, once one recognizes that many prices (and wages) are fairly sticky over short time intervals, the arbitrariness of the path of nominal prices (in the sense of their underdetermination by real factors alone) implies that the path of real activity, and the associated path of equilibrium real interest rates, are equally arbitrary. It is equally possible, from a logical standpoint, to imagine allowing the central bank to determine, by arbitrary fiat, the path of aggregate real activity, or the path of real interest rates, or the path of nominal interest rates, as it is to imagine allowing it to determine the path of nominal interest rates.[68] In practice, it is easiest for central banks to exert relatively direct control over overnight nominal interest rates, and so banks generally formulate their short-run objectives (their operating target) in terms of the effect that they seek to bring about in this variable rather than one of the others.

Even recognizing the existence of a very large set of rational expectations equilibria—equally consistent with optimizing private-sector behavior and with market clearing, in the absence of any specification of monetary policy—one might, nonetheless, suppose, as Fischer Black (1970) once did, that in a fully deregulated system the central bank should have no way of using monetary policy to select among these alternative equilibria. The path of money prices (and similarly nominal interest rates, nominal exchange rates, and so on) would then be determined solely by the self-fulfilling expectations of market participants. Why should the central bank play any special role in determining which of these outcomes should actually occur, if it does not possess any monopoly power as the unique supplier of some crucial service?

The answer is that the unit of account in a purely fiat system is defined in terms of the liabilities of the central bank.[69] A financial contract that promises to deliver a certain number of U.S. dollars at a specified future date is promising payment in terms of Federal Reserve notes or clearing balances at the Fed (which are treated as freely convertible into one another by Fed). Even in the technological utopia imagined by the enthusiasts of "electronic money"—where financial market participants are willing to accept as final settlement transfers made over electronic networks in which the central bank is not involved—if debts are contracted in units of a national currency, then clearing balances at the central bank will still define the thing to which these other claims are accepted as equivalent.

This explains why the nominal interest yield on clearing balances at the central bank can determine overnight rates in the market as a whole. The central bank can obviously define the nominal yield on overnight deposits in its clearing accounts as it chooses; it is simply promising to increase the nominal amount credited to a given account, after all. It can also determine this independently of its determination of the quantity of such balances that it supplies. Commercial banks may exchange claims to such deposits among themselves on whatever terms they like. But the market value of a dollar deposit in such an account cannot be anything other than a dollar—because this defines the meaning of a "dollar!" This places the Fed in a different situation than any other issuer of dollar-denominated liabilities.[70] Citibank can determine the number of dollars that one of its jumbo CDs will be worth at maturity, but must then allow the market to determine the current dollar value of such a claim; it cannot determine both the quantity that it wishes to issue of such claims and the interest yield on them. Yet, the Fed can, and does so daily—though as we have noted, at present, it chooses to fix the interest yield on Fed balances at zero and only to vary the supply. The Fed's current position as monopoly supplier of an instrument that serves a special function is necessary in order for variations in the quantity supplied to affect the equilibrium spread between this interest rate and other market rates, but not in order to allow separate determination of the interest rate on central-bank balances and the quantity of them in existence.

Yes, someone may respond, a central bank would still be able to determine the interest rate on overnight deposits at the central bank, and, thus, the interest rate in the interbank market for such claims, even in a world of completely frictionless financial markets. But would control of this interest rate necessarily have consequences for other market rates, the ones that matter for critical intertemporal decisions such as investment spending? The answer is that it must—and all the more so in a world in which financial markets have become highly efficient, so that arbitrage opportunities created by discrepancies among the yields on different market instruments are immediately eliminated. Equally riskless short-term claims issued by the private sector (say, shares in a money-market mutual fund holding very short-term Treasury bills) would not be able to promise a different interest rate than the one available on deposits at the central bank; otherwise, there would be excess supply or demand for the private-sector instruments. And determination of the overnight interest rate would also have to imply determination of the equilibrium overnight holding return on longer-lived securities, up to a correction for risk; and so, determination of the expected future path of overnight interest rates would essentially determine longer-term interest rates.

Could we privatize money? 3.2

The special feature of central banks, then, is simply that they are entities the liabilities of which happen to be used to define the unit of account in a wide range of contracts that other people exchange with one another. There is perhaps no deep, universal reason why this need be so; it is certainly not essential that there be one such entity per national political unit. Nonetheless, the provision of a well-managed unit of account—one in terms of which the equilibrium prices of many goods and services will be relatively stable—clearly facilitates economic life. And given the evident convenience of having a single unit of account be used by most of the parties with whom one wishes to trade, one may well suppose that this function should properly continue to be taken on by the government.

Nonetheless, it is worth remarking that there is no reason of principle for prohibiting private entry into this activity—apart from the usual concerns with the prevention of fraud and financial panics that require regulation of the activities of financial intermediaries in general. One might imagine, as Hayek (1986) did, a future in which private entities manage competing monetary standards in terms of which people might choose to contract. Even in such a world, the Fed would still be able to control the exchange value of the U.S. dollar against goods and services by adjusting the nominal interest rate paid on Fed balances. The exchange value of the U.S. dollar in terms of private currencies would depend upon the respective monetary policies of the various issuers, just as is true of the determination of exchange rates among different national currencies today.

In such a world, would central banks continue to matter? This would depend upon how many people still chose to contract in terms of the currencies the values of which they continued to determine. Under present circumstances, it is quite costly for most people to attempt to transact in a currency other than the one issued by their national government, because of the strong network externalities associated with such a choice, even though there are often no legal barriers to contracting in another currency. But in a future in which transactions costs of all sorts have been radically reduced, that might no longer be the case, and, if so, the displacement of national currencies by private payment media might come to be possible.[71] Would this be a disaster for macroeconomic stability?

It is hard to see why it should be. The choice to transact in terms of a particular currency, when several competing alternatives are available, would presumably be made on the basis of an expectation that the currency in question would be managed in a way that would make its use convenient. Above all, this should mean stability of its value, so that fixing a contract wage or price in these units will not lead to large distortions over the lifetime of the contract (or so that complicated indexation schemes will not need to be added to contracts to offset the effects of instability in the currency's value). Thus, competition between currencies should increase the chances that at least some of those available would establish reputations for maintaining stable values. Of course, the relevant sense in which the value of a currency should remain stable is that the prices of those goods and services *that happen to be priced in that currency* should remain as stable as possible.[72] Thus, one might imagine "currency blocs" developing in different sectors of a national economy between which there would be substantial relative-price variations even in the case of fully flexible prices, with firms in each sector choosing to transact in a currency that is managed in a way that serves especially to stabilize the prices of the particular types of goods and services in their sector.[73] The development of a system of separate currency blocs not corresponding to national boundaries, or to any political units at all, might then have efficiency advantages.

Thus, a future is conceivable in which improvements in the efficiency of communications and information processing so change the financial landscape that national central banks cease to control anything that matters to national economies. Yet, even such a development would not mean that nominal prices would cease to be determined by anything, and would be left to the vagaries of self-fulfilling expectations—with the result that, due to wage and price stickiness, the degree to which productive resources are properly utilized would be hostage to these same arbitrary expectations. Such a future could only occur if the functions of central banks today are taken over by private issuers of means of payment, who are able to stabilize the values of the currencies that they issue. And if in some distant future this important function comes to be supplied by private organizations, it is likely that they will build upon the techniques for inflation control being developed by central banks in our time.

Appendix
Market Participation and the Effectiveness of Open-Market Operations

The following simple model may help to clarify the point made in section 1.1 about the illusory benefit that derives from increasing the central bank's leverage over market rates by making the bank's interventions as much of a surprise as possible. Let the economy be made up of a group of households indexed by j, each of which chooses consumption C^j, end-of-period money balances M^j, and end-of-period bond holdings B^j, to maximize an objective of the form

$$u\left(C^j, M^j / P\right) + \lambda^j\left(M^j + (1+i)B^j\right), \tag{A.1}$$

where u is an increasing, concave function of consumption and real money balances, P is the current-period price level, i is the nominal interest yield on the bonds between the current period and the next, and $\lambda^j > 0$ is the household's discounted expected marginal utility of nominal wealth in the following period. I assume here for simplicity that the expected marginal utility of wealth λ^j is affected only negligibly by a household's saving and portfolio decisions in the current period, because the cost of consumption expenditure and the interest foregone on money balances for a single period are small relative to the household's total wealth; we, thus, treat λ^j as a given constant (though, of course, in a more complete model it depends upon expectations about equilibrium in subsequent periods, including future monetary policy).

Each household chooses these variables subject to a budget constraint of the form

$$M^j + B^j + PC^j \le W^j = \tilde{W}^j + \bar{B}^j, \tag{A.2}$$

where W^j is the household's nominal wealth to be allocated among the three uses. This last can be partitioned into the household's bond holdings $\bar{B}^j$ prior to the end-of-period trading in which the central bank's open-market operations are conducted and the other sources of wealth $\tilde{}^{j}$. I suppose, finally, that only a fraction γ of the households participate in this end-of-period bond trading; the choices of the other households are subject to the additional constraint that

$$B^j = \bar{B}^j, \tag{A.3}$$

whether or not this would be optimal in the absence of the constraint. Because advance notice of the central bank's intention to conduct an open-market operation will, in general, make the previously chosen $\bar{B}^j$ no longer optimal, I suppose that greater publicity would increase the participation rate γ; but I do not here explicitly model the participation decision, instead considering only the consequences of alternative values of γ. All households are assumed to choose their consumption and, hence, their end-of-period money balances only after the size of the open-market operation has been revealed; P and i are, thus, each determined only after revelation of this information.

Assuming an interior solution, the optimal decision of each household satisfies the first-order condition

$$u_c\left(C^j, M^j / P\right) - u_m\left(C^j, M^j / P\right) = \lambda^j P. \tag{A.4}$$

In the case of households that participate in the end-of-period bond market, there is an additional first-order condition

$$u_m\left(C^j, M^j / P\right) = \lambda^j P i. \tag{A.5}$$

Using (A.4) to eliminate λ^j in (A.5), one obtains a relation that can be solved (under the standard assumption that both consumption and real balances are normal goods) for desired real balance

$$M^j / P = L\left(C^j, i\right), \tag{A.6}$$

where the money demand function L is increasing in real purchases C^j and decreasing in the interest rate i. The optimal decisions of these households are then determined by (A.2), (A.4), and (A.5) (or equivalently (A.6)). The optimal decisions of the households that do not participate in the final bond trading are, instead, determined by the first two of these relations and by the constraint (A.3) instead of (A.5).

In the case of the non-participating households, these conditions have a solution of the form

$$C^j = c^{np}\left(\tilde{W}^j / P, \lambda^j P\right), \tag{A.7}$$

$$M^j / P = m^{np}\left(\tilde{W}^j / P, \lambda^j P\right). \tag{A.8}$$

Bond holdings are, of course, given by (A.3). Note that these households' decisions are unaffected by the bond yield i determined in the end-of-period trading. In the case of participating households, conditions (A.4) and (A.5) can instead be solved to yield

$$C^j = c^p\left(\lambda^j P, i\right), \tag{A.9}$$

$$M^j / P = m^p\left(\lambda^j P, i\right). \tag{A.10}$$

In the standard case, both c^p and m^p will be decreasing functions of i. The implied demand for bonds is then given by

$$B^j = \tilde{W}^j + \overline{B}^j - d\left(\lambda^j P, i\right), \tag{A.11}$$

where

$$d\left(\lambda^j P, i\right) \equiv c^p\left(\lambda^j P, i\right) + m^p\left(\lambda^j P, i\right).$$

Now, suppose that the central bank increases the money supply by a quantity ΔM per capita, through an open-market operation that reduces the supply of bonds by this same amount. The effect on the interest rate i is then determined by the requirement that participating households must be induced to reduce their bond holdings by an aggregate quantity equal to the size of the open market operation. The interest rate required for this is determined by aggregating (A.11) over the set of participating households. In the simple case that they are all identical, the equilibrium condition is

$$d\left(\lambda P, i\right) = \frac{\tilde{W} + \gamma^{-1}\Delta M}{P}, \tag{A.12}$$

as each participating household must be induced to sell γ^{-1} times its per capita share of the bonds purchased by the central bank. It is obvious that the resulting interest-rate decline is larger (for a given size of ΔM and a given price level) the smaller is γ. This is favored by "catching the markets off guard" when conducting an open-market operation.

But this need not mean any larger effect of the open-market operation on aggregate demand. The consumption demands of the fraction $1-\gamma$ of households not participating in the end-of-period bond market are independent of i. While the expenditure of the participating households (at a given price level P) is stimulated more as a result of the greater decline in interest rates (this follows from (A.9), there are also fewer of them. Thus there need be no greater effect on aggregate demand from the greater interest-rate decline.

Note that when the interest rate is determined by (A.12), the implied consumption demand on the part of participating households is given by

$$c^{p}(\lambda P, i) = c^{np}\left(\tilde{W} + \gamma^{-1}\Delta M, \lambda P\right).$$

This follows from the fact that the consumption of these households satisfies (A.2) and (A.4) just as in the case of the non-participating households, but with the equilibrium condition $B_t^j = \overline{B}_t^j - \gamma^{-1}\Delta \mathrm{M}$ instead of $B_t^j = \overline{B}_t^j$. Aggregate real expenditure is then given by

$$C = \gamma c^{np}\left(\tilde{W} + \gamma^{-1}\Delta M, \lambda P\right) + (1-\gamma) c^{np}\left(\tilde{W}, \lambda P\right).$$

The partial derivative of C with respect to ΔM, evaluated at $\Delta M = 0$, is equal to

$$\frac{\delta C}{\delta \Delta M} = c_1^{np}\left(\tilde{W}, \lambda P\right) > 0,$$

which is independent of γ as stated in the text.

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Endnotes

1 See equation (A.12) in the Appendix.

2 Blinder et al. (2001) defend secrecy with regard to foreign-exchange market interventions on this ground, though they find little ground for secrecy with regard to the conduct or formulation of monetary policy.

3 Allan Meltzer, however, assures me that his own intention was never to present this analysis as a normative proposal, as opposed to a positive account of actual central-bank behavior.

4 Yet even many proponents of that model of aggregate supply would not endorse the conclusion that it therefore makes sense for a central bank to seek to exploit its informational advantage in order to achieve output-stabilization goals. Much of the "New Classical" literature of the 1970s instead argued that the conditions under which successful output stabilization would be possible were so stringent as to recommend that central banks abandon any attempt to use monetary policy for such ends.

5 See Woodford (2001, chapter 3) for detailed discussion of the microeconomic foundations of the aggregate-supply relation (1.1), and comparison of it with the "New Classical" specification. Examples of recent analyses of monetary policy options employing this specification include Goodfriend and King (1997), McCallum and Nelson (1999), and Clarida et al. (1999).

6 See Woodford (2001, chapter 3) for further discussion. A number of recent papers find a substantially better fit between this equation and empirical inflation dynamics

when data on real unit labor costs are used to measure the "output gap," rather than a more conventional output-based measure. See, e.g., Sbordone (1998), Gali and Gertler (1999), and Gali et al., (2000).

[7] This is the foundation offered for the effect of interest rates on aggregate demand in the simple optimizing model of the monetary transmission mechanism used in papers such as Kerr and King (1996), McCallum and Nelson (1999), and Clarida et al. (1999), and expounded in Woodford (2001, chap. 4).

[8] Examples of recent discussions of the issue by central bankers include Issing (2001) and Jenkins (2001).

[9] We have mentioned above the important shift to immediate announcement of target changes since February 1994. Demiralp and Jorda (2001a) argue that markets have actually had little difficulty correctly understanding the Fed's target changes since November 1989. Lange et al. (2001) detail a series of changes in the Fed's communication with the public since 1994 that have further increased the degree to which it gives explicit hints about the likelihood of future changes in policy.

[10] It is crucial here to recognize that there is no unique equilibrium path for interest rates that markets would tend to in the absence of an interest-rate policy on the part of the central bank. See further discussion in Section 3.

[11] Giannoni and Woodford (2001) discuss how policy rules can be designed that can be specified without any reference to particular economic disturbances, but that, nonetheless, imply an optimal equilibrium response to additive disturbances of an arbitrary type. The targeting rules advocated by Svensson (2001) are examples of rules of this kind.

[12] A concrete example of such principles and how they can be applied is provided in Giannoni and Woodford (2001).

[13] Costa and De Grauwe (2001) instead argue that central banks are currently large players in many national financial markets. But they agree with Friedman that there is a serious threat of loss of monetary control if central bank balances sheets shrink in the future as a result of financial innovation.

[14] Henckel et al. (1999) review similar developments, though they reach a very different conclusion about the threat posed to the efficacy of monetary policy.

[15] Gormez and Capie (2000) report the results of surveys conducted at trade fairs for smart-card innovators held in London in 1999 and 2000. In the 1999 survey, 35 percent of the exhibitors answered "Yes" to the question "Do you think that electronic

cash has a potential to replace central bank money?" while another 47 percent replied "To a certain extent." Of those answering "Yes," 22 percent predicted that this should occur before 2005, another 33 percent before 2010, and all but 17 percent predicted that it should occur before 2020.

16 See, e.g., Bennett and Peristiani (2001).

17 For example, it accounts for more than 84 percent of central bank liabilities in countries such as the U.S., Canada, and Japan (Bank for International Settlements, 1996, Table 1).

18 See, e.g., McCallum (1999, sec. 5).

19 See Woodford (2001, chaps. 2 and 4) for an argument that "real-balance effects," a potential channel through which variation in monetary aggregates may affect spending quite apart from the path of interest rates, are quantitatively trivial in practice.

20 This is obviously true of a bank that, like the U.S. Federal Reserve since the late 1980s, uses open-market operations to try to achieve an operating target for the overnight rate; maintaining the fed funds rate near the target requires the Fed to prevent variations in the supply of Fed balances that are not justified by any changes in the demand for such balances. But it is also true of operating procedures such as the nonborrowed-reserves targeting practiced by the Fed between 1979 and 1982 (Gilbert, 1985). While this was a type of quantity targeting regime that allowed substantial volatility in the funds rate, maintaining a target for the supply of nonborrowed reserves also required the Fed to automatically accommodate variations in currency demand through open-market operations.

21 A somewhat more distant, but not inconceivable prospect is that "electronic cash" could largely replace payment by checks drawn on bank accounts, thus reducing the demand for deposits subject to reserve requirements. For a recent discussion of the prospects for e-cash as a substitute for conventional banking, see Claessens et al. (2001).

22 Again see Bennett and Peristiani (2001). Reductions in legal reserve requirements in 1990 and 1992 have contributed to the same trend over the past decade.

23 See Borio (1997), Sellon and Weiner (1996, 1997) and Henckel et al. (1999).

24 Roughly the same quantity of Fed balances represent "required clearing balances." These are amounts that banks agree to hold on average in their accounts at the Fed, in addition to their required reserves; the banks are compensated for these balances, in credit that can be used to pay for various services for which the Fed charges (Meulendyke, 1998, chap. 6). However, the balances classified this way do not fully

measure the demand for clearing balances. Banks' additional balances, classified as "excess reserves," are also held largely to facilitate clearing; these represent balances that the banks choose to hold ex post, above the "required balances" negotiated with the Fed in advance of the reserve maintenance period. Furthermore, the balances held to satisfy reserve requirements also facilitate clearing, insofar as they must be maintained only on average over a two-week period, and not at the end of each day. Thus, in the absence of reserve requirements, the demand for Fed balances might well be nearly as large as it is at present.

[25] Fluctuations in the net supply of overnight balances, apart from those due to central-bank open-market operations, occur as a result of government payments that are not fully offset by open-market operations, while fluctuations in the net demand for such balances by banks result from day-to-day variation in un-certainty about payment flows and variation in the efficiency with which the interbank market succeeds in matching banks with excess clearing balances with those that are short.

[26] This is emphasized by Furfine, for whom it is crucial in explaining how patterns in daily interbank payments flows can create corresponding patterns in daily variations in the funds rate. However, the system of compensating banks for committing themselves to hold a certain average level of "required clearing balances" over a two-week maintenance period introduces similar intertemporal substitution into the demand for Fed balances, even in the absence of reserve requirements.

[27] The increase in funds rate volatility in 1991 following the reduction in reserve requirements is often interpreted in this way; see, e.g., Clouse and Elmendorf (1997). However, declines in required reserve balances since then have to some extent been offset by increased holdings of required clearing balances, and this is probably the reason that funds rate volatility has not been notably higher in recent years.

[28] See also the views of electronic-money innovators reported in Gormez and Capie (2000). In the 2000 survey described there, 57 percent of respondents felt that e-money technologies "can ... eliminate the power of central banks as the sole providers of monetary base in the future (by offering alternative monies issued by other institutions)." And 48 percent of respondents predicted that these technologies would "lead to a 'free banking' era (a system of competing technologies issued by various institutions and without a central bank)." Examples of "digital currency" systems currently being promoted are discussed at the Standard Transactions website, http://www.standardtransactions.com/digitalcurrencies.html.

[29] Goodhart (1986) and McCulloch (1986), nonetheless, propose a method for paying interest on currency as well, through a lottery based upon the serial numbers of individual notes.

[30] For details of these systems, see, e.g., Archer et al., (1999), Bank of Canada

(1999), Borio (1997), Brookes and Hampton (2000), Campbell (1998), Clinton (1997), Reserve Bank of Australia (1998), Reserve Bank of New Zealand (1999), and Sellon and Weiner (1997).

31 Of course, standing facilities may be provided even in the presence of reserve requirements, as is currently the case at the European Central Bank. The ECB's standing facilities do not establish nearly so narrow a "channel" as in the case of Canada, Australia and New Zealand—except for a period in early 1999 just after the introduction of the euro, it has had a width of 200 basis points, rather than only 50 basis points —and open market operations in response to deviations of overnight rates from the target rate play a larger role in the control of overnight rates, as in the United States (European Central Bank, 2001). We also here abstract from the complications resulting from the U.S. regulations relating to "required clearing balances," which result in substitutability of clearing balances across days within the same two-week reserve maintenance period, as discussed above.

32 This is called the "target rate" in Canada and Australia, and the "official cash rate" (OCR) in New Zealand; in all of these countries, changes in the central bank's operating target are announced in terms of changes in this rate. The RBNZ prefers not to refer to a "target" rate in order to make it clear that the Bank does not intend to intervene in the interbank market to enforce trading at this rate. In Canada, until this year, the existence of the target rate was not emphasized in the Bank's announcements of policy changes; instead, more emphasis was given to the boundaries of the "operating band" or channel, and policy changes were announced in terms of changes in the "Bank Rate" (the upper bound of the channel). But the midpoint of the "operating band" was understood to represent the Bank's target rate (Bank of Canada, 1999), and the Bank of Canada has recently adopted the practice of announcing changes in its target rate (see, e.g., Bank of Canada, 2001b), in conformity with the practices of other central banks.

33 In New Zealand, the lending rate (Overnight Repo Facility rate) was briefly reduced to only 10 basis points above the OCR during the period spanning the "Y2K" date change, as discussed further below.

34 Economists at the RBA believe that there remains some small stigma associated with use of the Bank's lending (overnight repo) facility, despite the Bank's insistence that "overnight repos are there to be used," as long as the same bank does not need them day after day. Nonetheless, the facility is used with some regularity, and clearly serves a different function than the U.S. discount window. One of the more obvious differences is that in the U.S., the Fed consistently chooses a target funds rate that is above the discount rate, making it clear that there is no intention to freely supply funds at the discount rate, while the banks with channel systems always choose a target rate below the rate associated with their overnight lending facilities. Lending at the Fed's discount window is also typically for a longer term than overnight (say, for two weeks), and is thus not intended primarily as a means of dealing with daily overdrafts in clearing accounts.

[35] In each of the three countries mentioned, as leading examples of this kind of system, a "channel" width of 50 basis points is currently standard. However, the Reserve Bank of New Zealand briefly narrowed its "channel" to a width of only 20 basis points late in 1999, in order to reduce the cost to banks of holding larger-than-usual overnight balances in order to deal with possible unusual liquidity demands resulting from the "Y2K" panic (Hampton, 2000). It is also worth noting that when the Reserve Bank of Australia first established its deposit facility, it paid a rate only 10 basis points below the target cash rate. This, however, was observed to result in substantial unwillingness of banks to lend in the interbank market, as a result of which the rate was lowered to 25 basis points below the target rate (Reserve Bank of Australia, 1998).

[36] It is arguable that the actual lower bound is somewhat above the deposit rate, because of the convenience and lack of credit risk associated with the deposit facility, and similarly that the actual upper bound is slightly above the lending rate, because of the collateral requirements and possible stigma associated with the lending facility. Nonetheless, market rates are observed to stay within the channel established by these rates (except for occasional slight breaches of the upper bound during the early months of operation of Canada's system—see Chart 4), and typically near its center.

[37] This analysis is similar to a traditional analysis, such as that of Gilbert (1985), of federal funds rate determination under U.S. operating procedures. But under U.S. arrangements, there is no horizontal segment to the left (or rather, this occurs only at a zero funds rate), and the segment extending to the right is steeply sloped, owing to rationing at the discount window. In recent years, U.S. banks have indicated considerable reluctance to borrow at the discount window, so that the entire schedule may be treated as essentially vertical. However, a static analysis of this kind is only possible for the United States if the model is taken to refer to averages over a two-week reserve maintenance period, as Gilbert notes. Hence, the existence of a Trading Desk reaction function of the kind described by Taylor (2001), in which the Desk's open market operations each day respond to the previous day's discrepancy between the funds rate and the Fed's target, should give the effective supply schedule over a maintenance period an upward slope in the case of the United States.

[38] The account given here closely follows Henckel et al. (1999) and Guthrie and Wright (2000).

[39] In Furfine's (2000) model of the daily U.S. interbank market, this residual uncertainty represents the possibility of "operational glitches, bookkeeping mistakes, or payments expected from a counterparty that fail to arrive before the closing of Fedwire."

[40] In practice, lending in the interbank market is observed to occur at a rate above the central banks deposit rate, despite the existence of a positive net supply of clearing balances, even when there is a "closing period" at the end of the day in which

trades in the interbank market for overnight clearing balances are still possible while no further payments may be posted. Even though trading is possible at a time at which banks know the day's payment flows with certainty, it is sufficiently inconvenient for them to wait until the "closing period" to arrange their trades that a substantial amount of trading occurs earlier, and, hence, under uncertainty of the kind assumed in the model. The model's assumption that all trading in the interbank market occurs at a single point in time, and that the market is cleared at a single rate by a Walrasian "auctioneer," is obviously an abstraction, but one that is intended to provide insight into the basic determinants of the average overnight rate.

41 This need not equal the actual end-of-day supply, apart from borrowings from the lending facility, if there remains uncertainty about the size of government payments yet to be received by the end of the day.

42 Nontrivial discrepancies frequently exist between the target and actual supplies of clearing balances; see, e.g., Chart 2 in the case of Australia. The procedures used in Canada evidently allow precise targeting of the total supply of clearing balances; furthermore, the Bank of Canada's target level of balances for a given day is always announced by 4:30 p.m. the previous day (Bank of Canada, 2001a). Thus, for Canada, $u = 0$ each day.

43 In New Zealand, the "settlement cash target" since adoption of the OCR system has generally been fixed at $20 million NZ. At the Bank of Canada, the target level of clearing balances was actually zero during the early months of the LVTS system. But, as is discussed below, this did not work well. Since late in 1999, the Bank has switched to targeting a positive level of clearing balances, initially about $200 million Canadian, and higher on days when especially high transactions volume is expected (Bank of Canada, 1999, Addendum II). The target level is now ordinarily $50 million Canadian (Bank of Canada, 2001a). In Australia, the target level varies substantially from day to day (see Chart 2), but is currently typically about $750 million Australian.

44 This may be because the effective lower bound is actually slightly above the deposit rate, and the effective upper bound is slightly above the lending rate, as discussed in footnote 36. Hence, existing channel systems are not quite as symmetric as they appear.

45 Here, I abstract from possible effects upon the σ_i of changes in the volume of spending in the economy as a result of a change in the level of overnight interest rates. These are likely to be small relative to other sources of day-to-day variation in the σ_i and not to occur immediately in response to a change in the target overnight rate.

46 The Bank of Canada neutralizes the effects of payments to or from the government upon the supply of clearing balances through a procedure of direct transfer of

government deposits, but this technique has exactly the same effect as an open-market operation.

47 For example, given that this desired value is a small positive quantity, the Bank of Canada increases its target $\bar{S}$ on days when high transactions volume is expected, given that this higher volume of payments increases the uncertainty σ^i for the banks. Similarly, maintaining a constant expected supply of clearing balances $\bar{S}$ requires that predictable variations in currency demand or government payments be offset through open-market operations, and minimization of the variance of u requires the Bank to monitor such flows as closely as possible, and sometimes to trade more than once per day. For an illustration of the degree of variation that would occur in the supply of clearing balances in the case of New Zealand, if the RBNZ did not conduct daily "liquidity management operations" to offset these flows, see Chart 5 in Brookes (1999).

48 Of course, a substantial departure of the overnight rate from the target rate will suggest mis-estimation of the required supply of clearing balances (2.5), and this information is not ignored. In some cases, banks that operate a channel system even find a "second round" of open-market operations to be necessary, later in a given day, in order to correct an initial mis-estimate of the desired $\bar{S}$; and this is obviously in response to observed pressure on overnight rates in the interbank market. But in Australia and New Zealand, these are infrequent—in Australia, they were necessary only four times in 1999, never in 2000, and twice so far (as of September) in 2001. In Canada, small open-market operations are often conducted at a particular time (11:45 a.m.) to "reinforce the target rate" if the market is trading very far away from the target rate. However, this intervention does not amount to an elastic supply of funds at the target rate, and its effect upon the end-of-day supply of clearing balances is always canceled out later in the afternoon, so that the end-of-day supply equals the quantity announced by 4:30 p.m. the previous day. Thus, the supply curve for end-of-day balances in Canada is completely vertical at $\bar{S}$, as shown in Figure 1.

49 The deposit facility existed prior to June 1998, but the lending facility was introduced only in preparation for the switch to a real-time gross settlement (RTGS) system for interbank payments, and was little used prior to the introduction of that system in late June (Reserve Bank of Australia, 1998).

50 This is the level aimed at in the bank's initial daily open-market operations. As noted above, there are a few days on which the bank traded again in a "second round."

51 In New Zealand, the "settlement cash target" was increased by a factor of 10 in this period, with no effect at all upon actual overnight rates (Hampton, 2000).

52 The regime change was more dramatic in New Zealand at this time, as the RBNZ had not previously announced a target for overnight interest rates at all, instead formulating its operating target in terms of a "monetary conditions index." See Guthrie

and Wright (2000) for further discussion of New Zealand policy prior to the introduction of the OCR system.

53 Similar conventions appear to exist in Australia and Canada as well, but perhaps owing to larger size of these markets, trading is not so thoroughly determined by the norm as is true in New Zealand.

54 See Clinton (1997) and Bank of Canada (1999) for details of the system, and the connection between the change in the clearing system and the introduction of standing facilities for implementing monetary policy.

55 It is possible for the overnight rate to slightly exceed the Bank Rate when banks are short of the specific types of collateral accepted at the Bank of Canada's lending facility.

56 Since March 2000, the standard deviation of $i - i^*$ has been only 1.5 basis points for Australia, 1.1 basis points for Canada, and less than 0.4 basis points for New Zealand, but 13.4 basis points for the United States.

57 Special procedures adopted in Australia to deal with the "Y2K" panic are described in Reserve Bank of Australia (2000).

58 Canada has defined its short-run policy objectives in terms of an "operating band" for the overnight interest rate since June 1994, but did not use standing facilities to enforce the bounds of the band prior to the introduction of the LVTS clearing system in February 1999. Before then, intra-day interventions were used to prevent the overnight rate from moving outside the band (Sellon and Weiner, 1997). The adoption of systems based on standing facilities in both Australia and New Zealand also coincided with the introduction of a real-time gross settlement system for payments (Reserve Bank of Australia, 1998; Reserve Bank of New Zealand, 1999). In the case of New Zealand, an explicit operating target for the overnight rate (the "official cash rate") was also introduced only at this time.

59 Chari and Kehoe (1999) review recent literature showing that under an optimal Ramsey-taxation scheme the optimal level of this sort of tax is likely to be zero.

60 This may well have been a reason for the greater difficulty experienced in New Zealand at achievement of the RBNZ's short-run operating targets prior to the introduction of the OCR system in 1999. See Guthrie and Wright (2000) for discussion of New Zealand's previous approach to the implementation of monetary policy.

61 This seems to be the position of Goodhart (2000).

[62] This presumes a world in which no payments are cleared using central-bank balances. Of course, there would be no harm in continuing to offer such a facility as long as the central-bank clearing system were still used for at least some payments.

[63] Grimes (1992) shows that variation of the interest rate paid on central-bank balances would be effective in an environment in which central-bank reserves are no more useful for carrying out transactions than other liquid government securities, so that open-market purchases or sales of such securities are completely ineffective.

[64] Hall (1983, 1999) has also proposed this as a method of price-level control in the complete absence of monetary frictions. Hall speaks of control of the interest yield on a government "security," without any need for a central bank at all. But because of the special features that this instrument would need to possess, that are not possessed by privately issued securities—it is a claim only to future delivery of more units of the same instrument, and society's unit of account is defined in terms of this instrument—it seems best to think of it as still taking the same institutional form that it does today, namely, balances in an account with the central bank. Hall also proposes a specific kind of rule for adjusting the interest rate on bank reserves in order to ensure a constant equilibrium price level; but this particular rule is not essential to the general idea. One might equally well simply adjust the interest paid on reserves according to a "Taylor rule" or a Wicksellian price-level feedback rule (Woodford, 2001, chap. 2).

[65] It is true that required clearing balances are remunerated at a rate equal to the average of the federal funds rate over the reserve maintenance period. But this remuneration applies only to the balances that banks agree in advance to hold; their additional balances above this level are not remunerated, and so at the margin that is relevant to the decision each day about how to trade in the federal funds market, banks expect zero interest to be paid on their overnight balances.

[66] This does not mean that Wicksell's (1936) notion of a "natural" rate of interest determined by real factors is of no relevance to the consideration of the policy options facing a central bank. It is, indeed, as argued in Woodford (2001, chap. 4). But the natural rate of interest is the rate of interest required for an equilibrium with stable prices; the central bank, nonetheless, can arbitrarily choose the level of interest rates (within limits) because it can choose the degree to which prices shall increase or decrease.

[67] The basic point was famously made by Wicksell (1936, pp. 100-101), who compares relative prices to a pendulum that returns always to the same equilibrium position when perturbed, while the money prices of goods in general are compared to a cylinder resting on a horizontal plane, that can remain equally well in any location on the plane.

[68] This does not mean, of course, that absolutely any paths for these variables can be achieved through monetary policy; the chosen paths must be consistent with certain

constraints implied by the conditions for a rational-expectations equilibrium. But this is true even in the case of the central bank's choice of a path for the price level. Even in a world with fully flexible wages and prices, for example, it would not be possible to bring about a rate of deflation so fast as to imply a negative nominal interest rate.

69 See Hall (1999) and White (2001) for expression of similar views. White emphasizes the role of legal-tender statutes in defining the meaning of a national currency unit. But such statutes do not represent a restriction upon the means of payment that can be used within a given geographical region—or at any rate, there need be no such restrictions upon private agreements for the point to be valid. What matters is simply what contracts written in terms of a particular unit of account are taken to mean, and the role of law in stabilizing such meanings is essentially no different than, say, in the case of trademarks.

70 Costa and De Grauwe (2001) instead argue that "in a cashless society ... the central bank cannot 'force the banks to swallow' the reserves it creates" (p. 11), and speak of the central bank being forced to "liquidate...assets" in order the redeem the central-bank liabilities that commercial banks are "unwilling to hold" in their portfolios. This neglects the fact that the definition of the U.S. dollar allows the Fed to honor a commitment to pay a certain number of dollars to account-holders the next day by simply crediting them with an account of that size at the Fed—there is no possibility of demanding payment in terms of some other asset valued more highly by the market. Similarly, Costa and De Grauwe argue that "the problem of the central bank in a cashless society is comparable to [that of a] central bank pegging a fixed exchange rate" (footnote 15). But the problem of a bank seeking to maintain an exchange-rate peg is that it promises to deliver a *foreign currency* in exchange for its liabilities, not liabilities of its own that it freely creates. Costa and De Grauwe say that they imagine a world in which "the unit of account remains a national affair...and is provided by the state" (p. 1), but seem not to realize that this means defining that unit of account in terms of central-bank liabilities.

71 I should emphasize that I am quite skeptical of the likelihood of such an outcome. It seems more likely that there will continue to be substantial convenience to being able to carry out all of one's transactions in a single currency, and this is likely to mean that an incumbent monopolist—the national central bank—will be displaced only if it manages its currency spectacularly badly. But history reminds us that this is possible.

72 The connection between price stability and the minimization of economic distortions resulting from price or wage stickiness is treated in detail in Woodford (2001, chap. 6).

73 The considerations determining the desirable extent of such blocs are essentially the same as those in the literature on "optimal currency areas" in international economics.

References

Archer, David, Andrew Brookes, and Michael Reddell. "A Cash Rate System for Implementing Monetary Policy," Reserve Bank of New Zealand *Bulletin*, 62 pp. 51-61 (1999).

Bank for International Settlements. *Implications for Central Banks of the Development Electronic Money*, Basel, October 1996.

Bank of Canada. "The Framework for the Implementation of Monetary Policy in the Large Value Transfer System Environment," Web document, revised March 31, 1999; see also Addendum II, November 1999.

____________. "Changes to Certain Bank of Canada Operational Procedures Relating to the Large Value Transfer System and the Use of Purchases and Sales of Bankers' Acceptances in Managing the Bank of Canada's Balance Sheet," Web document, March 29, 2001a.

____________. "Bank of Canada Lowers Key Policy Rate by 1/4 Percent," press release, May 29, 2001b.

Barro, Robert J. "Unanticipated Money Growth and Unemployment in the United States," *American Economic Review*, 67 pp. 101-115 (1977).

____________ and Zvi Hercowitz. "Money Stock Revisions and Unanticipated Money Growth," *Journal of Monetary Economics*, 6 pp. 257-267 (1980).

Bennett, Paul, and Stavros Peristiani. "Are U.S. Reserve Requirements Still Effective?" unpublished, Federal Reserve Bank of New York, March 2001.

Black, Fischer. "Banking in a World without Money: The Effects of Uncontrolled Banking," *Journal of Bank Research*, 1 pp. 9-20 (1970).

Blinder, Alan S. *Central Banking in Theory and Practice*. Cambridge: MIT Press, 1998.

Blinder, Alan, Charles Goodhart, Philipp Hildebrand, David Lipton, and Charles Wyplosz. *How Do Central Banks Talk?* Geneva Report on the World Economy no. 3, International Center for Monetary and Banking Studies, 2001.

Bomfim, Antulio N. "Pre-Announcement Effects, News and Volatility: Monetary Policy and the Stock Market," Federal Reserve Board, FEDS paper no. 2000-50, November 2000.

Borio, Claudio E.V. *The Implementation of Monetary Policy in Industrial Countries:*

A Survey, Economic Paper no. 47, Bank for International Settlements, 1997.

Boschen, John, and Herschel I. Grossman. "Tests of Equilibrium Macroeconomics using Contemporaneous Monetary Data," *Journal of Monetary Economics*, 10 pp. 309-333 (1982).

Brookes, Andrew. "Monetary Policy and the Reserve Bank Balance Sheet," Reserve Bank of New Zealand *Bulletin* 62(4), pp. 17-33 (1999).

___________ and Tim Hampton. "The Official Cash Rate One Year On," Reserve Bank of New Zealand Bulletin, 63(2) pp. 53-62 (2000).

Calvo, Guillermo A. "Staggered Prices in a Utility-Maximizing Framework," *Journal of Monetary Economics*, 12 pp. 383-398 (1983).

Campbell, Frank. "Reserve Bank Domestic Operations under RTGS," Reserve Bank of Australia *Bulletin*, November 1998, pp. 54-59.

Chari, V.V., and Lawrence J. Christiano. "Optimal Fiscal and Monetary Policy," in J.B. Taylor and M. Woodford, eds., *Handbook of Macroeconomics,* vol. 1C, Amsterdam: North-Holland, 1999.

Christiano, Lawrence J., Martin Eichenbaum, and Charles Evans. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," unpublished, Northwestern University, May 2001.

Claessens, Stijn, Thomas Glaessner, and Daniela Klingebiel. *E-Finance in Emerging Markets: Is Leapfrogging Possible?* The World Bank, Financial Sector Discussion Paper no. 7, June 2001.

Clarida, Richard, Jordi Gali, and Mark Gertler. "The Science of Monetary Policy: A New Keynesian Perspective," *Journal of Economic Literature*, 37 pp. 1661-1707 (1999).

Clinton, Kevin. "Implementation of Monetary Policy in a Regime with Zero Reserve Requirements," Bank of Canada working paper no. 97-8, April 1997.

Clouse, James A., and Douglas W. Elmendorf. "Declining Required Reserves and the Volatility of the Federal Funds Rate," Federal Reserve Board, FEDS paper no. 1997-30, June 1997.

Cook, Timothy, and Thomas Hahn. "The Effect of Changes in the Federal Funds Rate Target on Market Interest Rates in the 1970s," *Journal of Monetary Economics*, 24 pp. 331-351 (1989).

Costa, Claudia, and Paul De Grauwe. "Monetary Policy in a Cashless Society," CEPR discussion paper no. 2696, February 2001.

Cukierman, Alex, and Allan Meltzer. "A Theory of Ambiguity, Credibility, and Inflation under Discretion and Asymmetric Information," *Econometrica*, 54 pp. 1099-1128 (1986).

Demiralp, Selva, and Oscar Jorda. "The Pavlovian Response of Term Rates to Fed Announcements," Federal Reserve Board, FEDS paper no. 2001-10, January 2001a.

__________ and __________. "The Announcement Effect: Evidence from Open Market Desk Data," unpublished, Federal Reserve Bank of New York, March 2001b.

European Central Bank. *The Monetary Policy of the ECB*, Frankfurt, 2001.

Freedman, Charles. "Monetary Policy Implementation: Past, Present and Future—Will Electronic Money Lead to the Eventual Demise of Central Banking?" *International Finance*, 3 pp. 211-227 (2000).

Friedman, Benjamin M. "The Future of Monetary Policy: The Central Bank as an Army with Only a Signal Corps?" *International Finance*, 2 pp. 321-338 (1999).

Furfine, Craig H. "Interbank Payments and the Daily Federal Funds Rate," *Journal of Monetary Economics*, 46 pp. 535-553 (2000).

Gali, Jordi, and Mark Gertler. "Inflation Dynamics: A Structural Econometric Analysis," *Journal of Monetary Economics*, 44 pp. 195-222 (1999).

__________, __________ and J. David Lopez-Salido. "European Inflation Dynamics," unpublished, Universitat Pompeu Fabra, October 2000.

Giannoni, Marc P., and Michael Woodford. "Optimal Interest Rate Rules," unpublished, Federal Reserve Bank of New York, August 2001.

Gilbert, R. Anton. "Operating Procedures for Conducting Monetary Policy," Federal Reserve Bank of St. Louis *Review*, February 1985, pp. 13-21.

Goodfriend, Marvin and Robert G. King. "The New Neoclassical Synthesis and the Role of Monetary Policy," *NBER Macroeconomics Annual*, 12 pp. 493-530 (1997).

Goodhart, Charles A.E. "How Can Non-Interest-Bearing Assets Coexist with Safe Interest-Bearing Assets?" *British Review of Economic Issues 8* (Autumn) pp. 1-12 (1986).

———. "Can Central Banking Survive the IT Revolution?" *International Finance* 3, pp. 189-209 (2000).

Gormez, Yuksel, and Forrest Capie. "Surveys on Electronic Money," Bank of Finland, discussion paper no. 7/2000, June 2000.

Grimes, Arthur. "Discount Policy and Bank Liquidity: Implications for the Modigliani-Miller and Quantity Theories," Reserve Bank of New Zealand, discussion paper no. G92/12, October 1992.

Guthrie, Graeme, and Julian Wright. "Open Mouth Operations," *Journal of Monetary Economics*, 24 pp. 489-516 (2000).

Hall, Robert E., "Optimal Fiduciary Monetary Systems," *Journal of Monetary Economics 12*, pp. 33-50 (1983).

——— "Controlling the Price Level," NBER working paper no. 6914, January 1999.

Hamilton, James. "The Daily Market in Federal Funds," *Journal of Political Economy*, 104 pp. 26-56 (1996).

Hampton, Tim. "Y2K and Banking System Liquidity," Reserve Bank of New Zealand *Bulletin 63*, pp. 52-60 (2000).

Hayek, Friedrich A. "Market Standards for Money," *Economic Affairs*, 6(4) pp. 8-10 (1986).

Henckel, Timo, Alain Ize, and Arto Kovanen. "Central Banking without Central Bank Money," IMF working paper no. 99/92, July 1999.

Issing, Ottmar. "Monetary Policy and Financial Markets," remarks to the ECB Watchers' Conference, Frankfurt, Germany, June 18, 2001.

Jenkins, Paul. "Communicating Canadian Monetary Policy: Towards Greater Transparency," remarks to the Ottawa Economics Association, Ottawa, Canada, May 22, 2001.

Kerr, William, and Robert G. King. "Limits on Interest Rates in the IS Model," Federal Reserve Bank of Richmond *Economic Quarterly*, Spring 1996, pp. 47-76.

King, Mervyn. "Challenges for Monetary Policy: New and Old," in New Challenges for Monetary Policy, Kansas City: Federal Reserve Bank of Kansas City, 1999.

Kuttner, Kenneth N. "Monetary Policy Surprises and Interest Rates: Evidence from the Fed Funds Futures Market," *Journal of Monetary Economics 47*, pp. 523-544 (2001).

Lange, Joe, Brian Sack, and William Whitesell. "Anticipations of Monetary Policy in Financial Markets," Federal Reserve Board, FEDS paper no. 2001-24, April 2001.

McCallum, Bennett T. "Issues in the Design of Monetary Policy Rules," in J.B. Taylor and M. Woodford, eds., *Handbook of Macroeconomics*, vol. 1C, Amsterdam: North-Holland, 1999.

__________ and Edward Nelson. "An Optimizing IS-LM Specification for Monetary Policy and Business Cycle Analysis," *Journal of Money, Credit and Banking 31*, pp. 296-316 (1999).

McCulloch, J. Huston. "Beyond the Historical Gold Standard," in C.D. Campbell and W.R. Dougan, eds., *Alternative Monetary Regimes*, Baltimore: Johns Hopkins University Press, 1986.

Meulendyke, Anne-Marie. *U.S. Monetary Policy and Financial Markets*, New York: Fed-eral Reserve Bank of New York, 1998.

Reserve Bank of Australia. "Operations in Financial Markets," Annual Report, Reserve Bank of Australia, 1998, pp. 28-43.

__________. "Operations in Financial Markets," Annual Report, Reserve Bank of Australia, 2000, pp. 5-18.

Reserve Bank of New Zealand. "Monetary Policy Implementation: Changes to Operating Procedures," Reserve Bank of New Zealand *Bulletin* 62(1), pp. 46-50 (1999).

Sbordone, Argia M. "Prices and Unit Labor Costs: A New Test of Price Stickiness," Stockholm University, IIES seminar paper no. 653, October 1998.

Sellon, Gordon H., Jr., and Stuart E. Weiner. "Monetary Policy Without Reserve Re-quirements: Analytical Issues," Federal Reserve Bank of Kansas City *Economic Review* 81(4), pp. 5-24 (1996).

__________ and __________. "Monetary Policy Without Reserve Requirements: Case Studies and Options for the United States," Federal Reserve Bank of Kansas City *Economic Review*, 82(2) pp. 5-30 (1997).

Spindt, Paul A., and Ronald J. Hoffmeister. "The Micromechanics of the Federal Funds Market: Implications for Day-of-the-Week Effects in Funds Rate Variability," *Journal of Financial and Quantitative Analysis,* 23 pp. 401-416 (1988).

Svensson, Lars E.O. "What is Wrong with Taylor Rules? Using Judgment in Monetary Policy through Targeting Rules," unpublished, Stockholm University, August 2001.

Taylor, John B. "Expectations, Open Market Operations, and Changes in the Federal Funds Rate," Federal Reserve Bank of St. Louis *Review*, 83(4) pp. 33-47 (2001).

White, Bruce. "Central Banking: Back to the Future," Reserve Bank of New Zealand, Discussion Paper, forthcoming 2001.

Wicksell, Knut. *Interest and Prices*, London: Macmillan, 1936 [orig. published in German, 1898].

Woodford, Michael. *Interest and Prices: Foundations of a Theory of Monetary Policy,* in preparation, Princeton University, August 2001.