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IMPLEMENTATION OF MONETARY POLICY:

HOW DO CENTRAL BANKS SET INTEREST RATES?*

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The making of monetary policy has changed significantly over the past quarter century. Most central banks have now abandoned the targets that they used to set for growth of one or another monetary aggregate, or at least have downgraded those targets from the focal role that they once played in the monetary policymaking process. Instead, both at the decision level and for purposes of policy implementation, what most central banks do, most of the time, is to set some short-term interest rate.

In parallel with this change in practice, the way in which economists and policymakers think and talk about monetary policy is different as well. With the intermediate link of money supply and money growth gone, the centerpiece of the discussion now is the relationship directly between the interest rate that the central bank fixes and the economic objectives—most prominently, the respective pace of price inflation and of real economic activity, but sometimes other considerations too—that policymakers are seeking to achieve. This difference at the conceptual level is likewise reflected in what economists write and teach about monetary policy. A generation ago, the simple analytical construct most widely used for these purposes was the Hicks-Keynes "ISLM" model based on the joint satisfaction of an aggregate equilibrium condition for the goods market (the "IS curve") and a parallel equilibrium condition for the money market for either given money supply or a given supply of bank reserves, in either case fixed by the central bank (the "LM curve"). The other quite widely used construct, following the

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work of Friedman and Schwartz, Cagan and others, was a "money multiplier" model according to which the reserve base fixed by the central bank determined the money stock (via the "money multiplier"), which in turn determined nominal income (via the "velocity" of money). Today, by contrast, the standard basic workhorse model used for macroeconomic and monetary policy analysis is the Clarida-Gali-Gertler "New Keynesian model" consisting of an IS curve, relating output to the interest rate as before but now including expectations of future output too, together with a Phillips-Calvo price-setting relation.

Importantly, what the central bank is assumed to determine in this model and in any of its many variants and elaborations—the primative for purposes of addressing monetary policy—is an interest rate. The money stock has disappeared from the analytical framework, as has the reserve base. So has the equilibrium condition represented by the old "LM curve." The same change is also reflected in more drawn-out and fundamental explorations of the subject. The title of Patinkin's classic treatise (1957, with an important revision in 1965), which shaped thinking in monetary economics for a generation, was *Money, Interest, and Prices*; Woodford's 2003 treatise was titled simply *Interest and Prices*. Similarly, Romer's widely used graduate textbook, *Advanced Macroeconomics* (1996, with revised editions in 2001 and again in 2006), includes no chapter on demand for money, supply of money, or money market equilibrium.

Taking the interest rate as a primitive for purposes of monetary policy analysis—or, alternatively, adding to the model a Taylor-type interest rate rule to represent the central bank's systematic behavior in choosing a level for the short-term interest rate—seems unproblematic from a practical perspective. Central banks do take and implement decisions about short-term interest rates. With few exceptions, they are able to make those decisions effective in the markets in which they operate. Even so, from a more fundamental viewpoint, simply starting from the fact that central banks implement monetary policy in this way leaves open the "how do they do that?" question. Nothing in today's standard workhorse model, nor in the analysis of Taylor rules, gives any clue to how the central bank actually goes about setting its chosen policy interest rate, or suggests any further elements worthy of attention in how it goes about doing so.

The traditional account of how this process works involves the central bank's varying the supply of bank reserves, or some other subset of its own liabilities, in the context of an interest-elastic demand for those liabilities on the part of the private banking system and perhaps other holders as well (including the nonbank public if the measure of central bank liabilities taken to be relevant includes ordinary currency in circulation). It is straightforward that the central bank has monopoly control over the supply of its own liabilities. What requires more explanation is that there is a demand for these liabilities, and that this demand is interest-sensitive. Familiar reasons for banks to hold central bank reserves include depositary institutions' need for balances with which to execute interbank transfers as part of the ordinary payment mechanism, their further need for currency to satisfy their customers' everyday demands (in systems, like that in the United States, in which vault cash is a part of banks' reserves), and in some systems (again the United States, for example) to satisfy outright reserve requirements imposed by the central bank. The negative interest elasticity follows as long as banks have at least some discretion in the amount of reserves that they hold for any or all of these purposes, and the interest that they earn on their reserve holdings differs from the appropriately risk-adjusted rates of return associated with alternative assets to which they have access. Although this long-standing story has now largely disappeared from most professional discussion of monetary policy, and from graduate-level teaching of macroeconomics, it remains a staple of undergraduate money-and-banking texts.

What has been problematic in this traditional account, however—if anything, what has become more so in recent decades—is the absence of any clearly visible empirical relationship between the interest rates that most central banks are setting and the quantities of reserves that they are supplying. A substantial empirical literature, dating from the 19__s and even earlier, has sought to identify a "liquidity effect" by which changes in the supply of bank reserves induce changes in the central bank's policy interest rate and, from there, changes in other market-determined short-term interest rates as well. For a phenomenon that supposedly underlies such a familiar and important aspect of economic policymaking, this effect has been notoriously difficult to document empirically. Even when researchers have found a significant relationship, the estimated magnitude has often been hard to reconcile with the context of actual central bank monetary policymaking. Further, developments within the most recent twenty years have rendered the relationship even more problematic.

In the United States, until this decade, the evidence suggested that the amount by which the Federal Reserve System increased or decreased bank reserves in order to move the prevailing federal funds rate (the overnight interest rate on interbank transfers of reserves) was not only extremely small, compared to the size of the markets in which U.S. banks operate, but becoming smaller over time. Indeed, on many occasions moving the federal funds rate appears to have required no, or almost no, central bank transactions at all. Since 2000 the amount by which reserves have changed on days of policy-induced changes in the federal funds rate has become noticeably larger on average. But in a significant fraction of cases—one-third to one-fourth of all changes in the federal funds rate—the movement in reserves has been *in the wrong direction*: the movement that accompanied a decline in the interest rate (for example, during the period of monetary policy easing in 2000-1) was sometimes a *decrease* in reserves, and the movement that accompanied an increase in the interest rate (during the period of policy tightening in 2004-6) was sometimes an *increase* in reserves! The point, of course, is not that the "liquidity effect" sometimes has one sign and sometimes the other. Rather, at least on a same-day basis, even in the post-2000 experience the movement in reserves associated with a policy-induced change in the federal funds rate is sufficiently small to be impossible to distinguish from the normal day-to-day variation in reserve supply needed to offset fluctuations in float, or Treasury balances, or other non-policy factors that routinely affect banks' reserve demand.

A further aspect of the puzzle surrounding central banks' setting of interest rates is the absence of any visible reallocation of banks' portfolios. The reason the central bank changes its policy interest rate is normally to influence economic activity, but few private borrowers whose actions matter for that purpose borrow at the federal funds rate. The objective, therefore, is to move other borrowing rates, and indeed the evidence indicates that this is usually what happens: changes in the central bank's policy rate lead to changes in private short-term rates as well. But the traditional story of how changes in the federal funds rate are transmitted to other interest rates involves banks' increasing their loans and investments when reserves become more plentiful/less costly, and cutting back on loans and investments when reserves become less plentiful/more costly. What is missing empirically is not the end result—to repeat, other short-term market interest rates do adjust when the federal funds rate changes, and in the right direction—but any evidence of the mechanism that is supposedly bringing this result about.

This goal of this chapter is to place these empirical puzzles in the context of the last two decades of research bearing on how central banks set interest rates, and to suggest avenues for understanding this process that are more consistent with contemporary monetary policy practice than the usual textbook accounts that have survived despite how this practice has changed. Section 1 begins by briefly recounting the evolution of monetary policymaking over this period, away from a focus on money supply and money growth targets toward (actually, back to) reliance on setting interest rates. Section 2 anchors this policy-level analysis in more fundamental thinking by drawing links to the more theoretically oriented literature of monetary policy in the absence of an explicit role for "money" per se. Section 3 reviews the empirical literature of the "liquidity effect," including several important subsidiary lines of analysis intended to address the basic empirical puzzle by incorporating specific relevant features of banking institutions. Section 4 suggests a modified analytical framework designed to permit a more effective analysis, and presents new sets of empirical estimates, for the United States, for the Euro area, and for Japan, based on current data. Section 5 interprets these empirical results and draws some broader implications. Section 6 digresses to review those actions of the Federal Reserve System, the European Central Bank and the Bank of Japan during the "Great Recession" of 2007-? that stand outside the now-conventional rubric of monetary policy as interest rate setting. Section 7 concludes.

1. From Targeting Money Growth to Setting Interest Rates

Historically, what came to be called "monetary" policy has primarily meant the fixing of some interest rate—and hence often a willingness to lend at that rate—by a country's central bank or some other institution empowered to act as if it were a central bank. Under the gold standard's various incarnations, raising and lowering interest rates was mainly a means to stabilize a country's gold flows and thereby enable it to maintain the gold-exchange value of its currency. For the first few decades following World War II, with most countries no longer on gold as a practical matter, setting interest rates and exchange rates per se emerged as central banks' way of regulating economic activity. As rapid and seemingly chronic price inflation spread through much of the industrialized world in the 1970s, however, most of the major central banks responded by increasingly orienting their monetary policies around control of money growth. By the end of that decade, the central banks of Australia, Canada, France, Germany, Japan, Switzerland, the United States and the United Kingdom all had formal growth targets for one or another monetary aggregate.[1]

[1] The German Bundesbank adopted a formal money growth target, for "central bank money," beginning in 1974. The Swiss National Bank and the Bank of Canada did so in 1975, in both cases with targets for M1. The U.S. Federal Reserve System also began to set money targets in 1975, with stated targets for M1, M2 and M3, although it is unclear that these targets

Because policymakers mostly chose to focus on measures of outstanding deposits and currency, as opposed to bank reserves, over time horizons like a year (or even longer) the magnitudes that they designated for the growth of these aggregates were necessarily targets to be pursued rather than instruments to be set. Deposits are demanded by households and firms, and supplied by banks and other issuers, in both cases in ways that are subject to central bank influence but not direct central bank control; and although a country's currency is typically a direct liability of its central bank, and hence in principle subject to exact control, in modern times no central bank has attempted to ration currency as a part of its monetary policymaking process. Merely comparing realized money growth to the previously stated target, after the fact for any given country in any given time period, is therefore insufficient to determine whether that country's central bank was actually seeking to achieve its target. More informative ways of addressing the question typically showed that most central banks among the larger industrialized economies were, at least in part, attempting to do so.

For the United States, for example, adding the most recently observed departure of money from the targeted value to a standard Taylor-rule representation of the Federal Reserve System's interest rate setting behavior,

$$r^F{}_t = b_0 + b_1\pi_{t-1} + b_2\pi_{t-2} + b_3(U - U^*)_{t-1} + b_4(U - U^*)_{t-2} + b_5(m - m^T)_{t-1} + u_t\,, \qquad (1\text{-}1)$$

in which r^F represents the fed funds rate, π is inflation, U and U^* are respectively the unemployment rate and an estimate of the natural rate, and m and m^T represent the log of the money stock and the Fed's prescribed target. The estimates indicate a statistically significant response of the federal funds rate, in the direction presumably corresponding to an attempt to bring money growth back within the target range (a higher interest rate when money has grown too rapidly, and vice versa) for periods that roughly correspond to the first half of the 1980s. The federal funds rate exhibited a significant response of this kind to the M1 money stock beginning in either 1979 or 1980. For M2 the period when a significant response was evident began in mid 1980. Further, the evidence suggests a much larger response—for the M1 target, on average 148 basis points of change in the interest rate for every 1 percent in the observed movement of

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played a significant role in actual monetary policymaking until 1979. The Bank of England followed, with a target for "Sterling M3," beginning in 1976, the Reserve Bank of Australia (M3) in the same year, the Banc de France (M2) in 1977, and the Bank of Japan (initially M2, modified to M2 plus certificates of deposit a year later) in 1978.

money away from the target (versus only 30 basis points at other times)—during the period from October 1979 through September 1982 when the Federal Reserve publicly placed the greatest emphasis on its money growth targets in explaining its policy and employed a specific day-to-day operating procedure, based on limiting the growth of banks' nonborrowed reserves, in order to achieve them.[2]

Monetary targeting proved short-lived, however. After September 1982 the Federal Reserve relaxed its focus on achieving its money growth targets, and it also abandoned the nonborrowed reserves operating procedure it had used during the prior three years. The response of the federal funds rate to departures of M1 from target ceased to be statistically significant some time in 1986. After 1986 the Federal Reserve discontinued even designating a target for M1 growth. By late 1986 the interest rate response to departures of M2 growth likewise ceased to be statistically significant, and there is no evidence that it ever became so again. In 1993 the Federal Reserve publicly "downgraded" its M2 target. Although it continued for some years thereafter to specify numerical growth ranges for both M2 and M3, in its public statements it made clear that these ranges did not serve as targets; they were merely expectations of what would happen under specific assumed conditions. In 1998 the Federal Reserve further clarified that these growth ranges were not "guides to policy." In 2001 it stopped setting such ranges altogether.

The U.S. experience in turning away from targeting money growth was representative of what ensued in most, though not all, other countries as well. The Bank of England dropped its Sterling M3 growth target in 1986, although there is little evidence that the target had played a significant role in the bank's policymaking for at least two years before then.[3] The Bank of Japan and the Reserve Bank of Australia abandoned their money growth targets the same year. The Bank of Canada did so in 19__, and the Banc de France in 19__. By contrast, the Swiss

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[2] See, for example, Friedman and Kuttner (1996); the estimates described here relied on a monthly regression model with time-varying coefficients, computed from a Kalman filter, and each month's estimate relied only on real-time data through that month (so that it corresponded to the behavior of monetary policy as observers at that point in time could have assessed it). But the general character of estimates like these is not closely dependent on the specific empirical techniques applied; see, for example, Friedman (1997).

[3] See Bernanke et al. (1999), pp. 149-150.

national bank retained its target for M1 growth, at least on a formal basis, until 2000. The German Bundesbank continued to target central bank money growth until it ceased running an independent monetary policy in 1999, and with the establishment of the European Central Bank what had been the Bundesbank's money targeting policy evolved into a partial focus on growth of Euro-area M3 as the "first pillar" of the bank's two-part monetary policy strategy. For the ECB as well, however, the evidence is mixed on the actual role that this element of the policymaking process has played, and the bank itself has not represented its procedures as money growth targeting.[4]

The reasons for this wholesale abandonment of monetary targeting, after what in retrospect seems a very short period of reliance on them (especially short compared to the vast literature of the subject that preceded this brief experiment), are straightforward and, by now, well known.[5] From the start in most countries it became apparent that, over time horizons that mattered importantly for monetary policy, different monetary aggregates within the same economy exhibited widely disparate growth rates. Hence an essential ingredient to policymaking under this rubric was knowledge of which specific measure of money presented the appropriate benchmark to which to respond—something that the existing empirical literature had not settled (and still has not). More fundamentally, changes in conditions affecting the public's holding of deposits destabilized what had at least appeared to be long-standing regularities in the demand for any one measure of money. The financial industry's introduction of new electronic technologies made possible both new forms of deposit-like instruments (money market mutual funds, for example) and new ways for both households and firms to manage their money holdings (like sweep accounts for firms and third-party credit cards for households). In many countries banking deregulation furthered this process (for example, removal of interest rate limits on consumer deposits in the United States, which permitted banks to offer money market deposit accounts). The increasing globalization of the world's financial system, itself a product of the new electronic technology but driven by other powerful forces as well, also mattered in that large deposit holders were increasingly able to substitute across national boundaries in the deposits and alternative instruments they held in their portfolios.

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[4] See Fischer et al. (2008) for a thorough discussion.

[5] See, for example, ___________ (19__).

As a result, standard models of the demand for money no longer exhibited their familiar stability.[6] A sizeable literature soon developed, showing that defining a given aggregate in a new way, or allowing for one or more structural breaks, would restore the appearance of stability. But such after-the-event corrections were not helpful for purposes of forward-looking policy—at least not in the absence of confidence that the most recent such redefinition would be the last. (Between 19__ and 19__ the Federal Reserve changed its official monetary aggregate definitions __ times.)

More directly relevant to the role of monetary targets in the policymaking process, the empirical relationships linking money growth to the increase of either prices or income—what had been the core empirical underpinning of the insight that limiting money growth would slow price inflation in the first place—began, in one country after another, to unravel. Standard statistical exercises that for years had shown a reasonably stable relationship of money growth to either inflation or nominal income growth (specifically, stable enough to be reliable for policy purposes) no longer did so. For the United States, ordinary regression analysis showed that M1 growth ceased to be statistically significant in explaining the movement of prices at a quarterly frequency (after controlling for real output and the short-term interest rate, and past movements of the price level itself) after 1982, and that from 1975 on M1 was never significant in corresponding regressions for the movement of output. M2 growth was not significant from 1975 on in regressions for either prices or output. Parallel analyses based on vector autoregression systems including prices, output, money and an interest rate showed that M1 growth accounted for a small but statistically significant share of the observed variance of prices only through 1982, while the M1 contribution to the variance of output remained marginally significant until 1987. Analogous vector autogregression analysis for M2 growth also showed a significant contribution to price variance ending after 1982, but none to output variance within this period.[7]

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[6] Ironically, the destabilization of money demand in some countries had become a focus of attention just as central banks were beginning to adopt money growth targets; see Goldfeld and Sichel (1990) for a survey. In the United States, however, the hard-to-explain movements of money demand that were evident in this early period turned out to be in the opposite direction from those that appeared later, after the Federal Reserve adopted its money growth targets.

[7] See again Friedman and Kuttner (1996). Here again, this line of inquiry spawned a large empirical literature, and some researchers did find effects of money growth, especially M1,

In the absence of targets for money growth, most central banks turned (again) to setting interest rates as a way of making monetary policy without any specific intermediate target. With the memory of the inflation of the 1970s and early 1980s still freshly in mind, however, policymakers in many countries were also acutely aware of the resulting lack of any "nominal anchor" for the economy. Interest rates, including nominal interest rates, are *relative* prices: an interest rate is the price of money today in terms of money at some future time. Especially before the familiar money-price and money-income relationships collapsed, there appeared to be ground for confidence that as long as the central bank held money growth to some modest pace, prices could not increase (or decrease) too much over time, nor at too rapid a rate. Nothing about holding some interest rate fixed offered this reassurance.

In response, an increasing number of central banks, beginning with the Reserve Bank of New Zealand in 1989 and both the Banco Central de Chile and the Bank of Canada in 1991, adopted various forms of "inflation targeting." As Tinbergen had pointed out long before, in the absence of a degeneracy the solution to a problem with one instrument and multiple targets can always be expressed in terms of the intended trajectory for any one designated target.[8] Monetary policy has, for practical purposes, one instrument to set (either a short-term interest rate or the quantity of some subset of central bank liabilities). Inflation targeting, therefore, need not imply that policymakers take the economy's inflation rate to be the sole objective of monetary policy.[9] The point, rather, is that under most familiar versions of the Phelps-Friedman natural rate model whatever trade-off exists between inflation and the real economic outcomes that policymakers might also seek to influence obtains only over some short- to medium-run horizon. Hence the supposed conceptual appeal of inflation targeting, following the Tinbergen principle, is to anchor expectations of future inflation by describing the aims of monetary policy in terms of the

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that persisted over longer sample periods; see Stock and Watson (1989), but see also Friedman and Kuttner (1993).

[8] See Tinbergen (1952).

[9] This point is most explicit in the work of Svensson (1997). As a practical matter, King (1997) has argued that few central bankers are what he called "inflation nutters." Although some central banks (most obviously, the ECB) at least purport to place inflation above other potential policy objectives in a strict hierarchy, whether they actually conduct monetary policy in this way is unclear.

trajectory for a variable that monetary policy can presumably affect in the long as well as the short run, and that in the long run monetary policy ought to be able to determine fully.[10]

For purposes of implementation of monetary policy, however, what matters regardless of policymakers' relative weighting of inflation and real outcomes is that the economy's inflation rate, much more than the rate of money growth, stands at far remove from anything that the central bank can plausible control in any direct way or over shorter horizons. Hence whether the central bank explicitly targets inflation (as the Bank of England does, for example), or does so only implicitly (as is often alleged for the ECB) or pursues an explicit dual objective involving both inflation and employment (as is the case, by law, for the U.S. Federal Reserve System) does not matter for these purposes. In each of these cases, the central bank has to implement monetary policy on a day-to-day and month-to-month basis by setting the value of some instrument over which it actually exerts direct control. For most central banks in recent years, and certainly for those in the advanced industrial economies, that has meant setting a short-term interest rate.

2. Theoretical Implications of Conducting Monetary Policy by Setting an Interest Rate

Economists have long recognized that fixing an interest rate potentially presents fundamental problems. The basic economic principle at issue is quite general. Whenever someone (the government, or perhaps a private firm) fixes a relative price, two possible classes of outcomes ensue. If whoever is fixing the relative price merely enforces the same price relation that the market would reach on its own, then fixing it does not matter. If the relative price is fixed differently from what the market would produce, however, private agents have incentives to substitute and trade in ways they would otherwise not want to do. Depending on the price elasticities applicable to the goods in question, the quantitative extent of the substitution and trading motivated in this way—arbitrage, in common parlance—can be either large or small.

When the specific relative price being fixed is an interest rate (that is, the rate of return to holding some asset) and when the entity fixing it is the central bank (that is, the provider of the economy's money), the matters potentially involved in this line of argument also assume

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[10] Whether inflation targeting actually serves this purpose, and whether the procedure embodies other potential drawbacks, is a matter of debate; see, for example, Friedman (2004) and Mishkin (2004).

macroeconomic significance, extending to the quantity and rate of growth of the economy's productive capital stock and the level and rate of increase of absolute prices. More than a century ago, Wicksell (1907) articulated the potential inflationary or deflationary consequences of what came to be known as interest rate "pegging": "If, other things remaining the same, the leading banks of the world were to lower their rate of interest, say 1 per cent. below its ordinary level, and keep it so for some years, then the prices of all commodities would rise and rise and rise without any limit whatever; on the contrary, if the leading banks were to *raise* their rate of interest, say 1 per cent. above its normal level, and keep it so for some years, then all prices would *fall* and fall and fall without any limit except Zero."[11] (It is interesting, in light of the emphasis of recent years on providing a "nominal anchor," that Wicksell thought that keeping prices stable would be *less* of a problem in a pure paper-money economy freed from the gold standard: "if the free coining of gold, like that of silver, should cease, and eventually the bank-note itself, or rather the unity in which the accounts of banks are kept, should become the standard of value, then, and not until then, the problem of keeping the value of money steady, the average level of money prices at a constant height, which evidently is to be regarded as the fundamental problem of monetary science, would be solvable theoretically and practically to any extent.")

As Wicksell explained, his proposition was not simply a mechanical statement connecting interest rates and inflation (or deflation) but rather the working out of an economic model that had as its centerpiece "the productivity and relative abundance of real capital": "the upward movement of prices, whether great or small in the first instance, *can never cease* so long as the rate of interest is kept lower than its normal rate, *i.e.*, the rate consistent with the then existent marginal productivity of real capital." Wicksell made clear that the situation he described was purely hypothetical. No one had observed—or, he thought, would observe—an economy's price level increasing or falling without limit. The remaining question, however, was what made this so. Was it merely that banks never would make their interest rates depart from the "normal rate" anchored to the economy's marginal product of capital? And what if somehow they did: Would the marginal product of capital ultimately move into alignment? If so, what

[11] Here and below, italics in quotations are in the original.

change in the economy's capital stock, and in the corresponding investment flows along the transition path, would be required?

Sargent and Wallace (1975) highlighted Wicksell's proposition in a different context by showing that in a traditional short-run ISLM model, but with flexible prices and "rational" (in the sense of model-consistent) expectations, identifying monetary policy as fixing the interest rate led to an indeterminacy. Under those conditions the model would devolve into two disconnected sub-models: one, over-determined, including real output and the real interest rate; the other, under-determined, including the price level and the money stock (and, by extension, the nominal interest rate). Hence with an exogenous interest rate the price level would be indeterminate—not as a consequence of the central bank's picking the wrong level for the interest rate, but no matter what level it chose. Moreover, given such assumptions as perfect price flexibility, what Wicksell envisioned as the potentially infinite rise or fall of prices over time translated into indeterminacy immediately.

Parkin (1978) and McCallum (1981) subsequently showed that although this indeterminacy would obtain under the conditions Sargent and Wallace specified if the central bank chose the exogenous interest rate level arbitrarily, it would not if policymakers instead fixed the interest rate at least in part as a way of influencing the money stock.[12] But the same point held for the price level, or, for that matter, any nominal magnitude. Even if the price level (or its rate of increase) were just one argument among others in the objective function policymakers were seeking to maximize, therefore—and, in principle, even if the weight they attached to it were small compared to that on output or other arguments—merely including prices (or inflation) as a consideration in a systematically responsive policy would be sufficient to break the indeterminacy.

Taken literally, with all of the model's implausible assumptions in force (perfectly flexible prices, model-consistent expectations, and so on), this result too strains credibility. It is difficult to believe that whether an economy's price level is determinate or not hinges on whether the weight its central bank places on inflation in carrying out monetary policy is almost zero or actually zero. But in Wicksell's context, with prices and wages that adjust over time, the insight rings true: If the central bank simply fixes an interest rate without any regard to the evolution of

[12] See also McCallum (1983, 1986).

nominal magnitudes, there is nothing to prevent a potentially infinite drift of prices; to the extent that it takes nominal magnitudes into account and systematically resets the interest rate accordingly, that possibility is precluded. The aspect of Wicksell's original insight that this line of inquiry still leaves unexplored, however, is how, even if there is no problem of indeterminacy of the aggregate price level, the central bank's fixing a relative price that bears some relation to the marginal product of capital potentially affects asset substitutions and, ultimately, capital accumulation.

Taylor's (1993) work on interest rate rules for monetary policy indirectly addressed the indeterminacy issue but left aside the implications of a central bank's fixing an interest rate for private asset substitutions and capital accumulation. Taylor initially showed that a simple rule relating the federal funds rate to observed values of inflation and the output gap, with no elaborate lag structure and with the two response coefficients simply picked as round numbers (1½ and ½, respectively), roughly replicated the Federal Reserve's conduct of monetary policy during 1987-92. This finding quickly spurred interest both in seeing whether similarly simple rules likewise replicated monetary policy as conducted by other central banks, or by the Federal Reserve during other time intervals.[13] It also prompted analysis of what choice of coefficient values would represent the optimal responsiveness of monetary policy to inflation and to movements of real economic activity.[14]

The aspect of this line of analysis that bore in particular on the Wicksell/Sargent-Wallace indeterminacy question concerned the responsiveness to observed inflation. For a general form of the "Taylor rule" as in

$$r^F_t = \alpha + \beta(\pi_t - \pi^*) + \gamma(y_t - y^*_t) \,, \tag{2-1}$$

where r^F is the interest rate the central bank is setting, π and π^* are, respectively, the observed inflation rate and the corresponding rate that policymakers are seeking to achieve, and y and y^* are, respectively, observed output and "full employment" output, the question turns on the magnitude of beta. (If the terms in $\pi - \pi^*$ and $y - y^*$ have some nontrivial lag structure, what matters for this purpose is the sum of the coefficients analogous to beta.) Friedman (19__), Brunner and Meltzer (1964) and others had earlier argued that, under forms of monetary

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[13] Prominent early examples include ________________________________.

[14] See, for example, _________________________________.

policymaking that are equivalent to the central bank's setting an interest rate, it was not uncommon for policymakers to confuse nominal and real interest rates in a way that led them to think they were tightening policy in response to inflation when in fact they were easing it. The point was that if inflation expectations rise one-for-one with observed inflation, as would be consistent with a random-walk model, then any response of the nominal interest rate that is less than one-for-one results in a lower rather than higher real interest rate. In what later became known as the "Taylor principle," Taylor (19__) formalized this insight as the proposition that beta in interest rate rules like (2-1) above must be greater than unity for monetary policy to be exerting an effective counter-force against an incipient inflation.

Together with a model in which inflation responds to monetary policy with a lag—for example, a standard New Keynesian model in which inflation responds to the level of output via a Calvo-Phillips relation, while output responds to the expected real interest rate via an "IS curve," with a lag in at least one relation if not both—the Taylor principle implies that if beta < 1, then once inflation exceeds π^* the expectation is for it to rise ever over time with no limit. Under this dynamic interpretation of what an indeterminate price level would mean, as in Wicksell, Parkin's and McCallum's argument that *any* positive weight on inflation would suffice to pin down the price level, no matter how small, clearly does not obtain. (In Parkin's and McCallum's original argument, the benchmark for considering the magnitude of beta was gamma; here, the relevant benchmark is instead an absolute: 1.) Because of the assumed lag structure in the Calvo-Phillips and/or IS relation, however, an immediate indeterminacy of the kind posited by Sargent and Wallace does not arise.

More recent literature, likewise prompted by the recognition that after the brief experiment with money growth targeting most central banks had returned to short-term nominal interest rates as the principal focus of their monetary policy decision making, has sought to explore whether there might yet be some different role for monetary quantities in the "monetary" policy process. McCallum (2001) pointed out that any model in which the central bank is assumed to set an interest rate is inherently a monetary model, regardless of whether it explicitly includes any monetary quantity, because the central bank's control over the chosen interest rate presumably stems from its ability to control the quantity of its own monetary liabilities. McCallum also argued that if the marginal benefit to holding money (from reduced transactions costs) increases with the volume of real economic activity, then the model is properly "monetary" in yet a further way: in principle the "IS curve" should include an additional term—that is, in addition to the real interest rate and the expected future level of output—reflecting the difference between the current money stock and what households and firms expect the money stock to be in the future.[15] His empirical analysis, however, showed no evidence of a statistically significant effect corresponding to this extra term in the relationship.

By contrast, Nelson (2002) showed that movements of the monetary base (not the difference between the base and some expected future value, as would be implied by McCallum's argument) are statistically significant in explaining real output, for both the United Kingdom and the United States, in "IS curve" relationships that control for both lagged output and a real short-term interest rate.[16] Nelson's explanation, following both Friedman's (1959) and Tobin's (1969) broadly portfolio-theoretic approach to the demand for money, was that money demand depends not just on short-term interest rates but long-term rates as well. Solving out the money demand function therefore implies that in the presence of both short-term rates and output the quantity of money is, in part, a reflection of long-term interest rates—and hence of the expectations of future output that these long-term rates embody. Given that neither country's central bank was conducting monetary policy by fixing its monetary base during the sample period used in this analysis (1982-97 for the U.K., 1980-99 for the U.S.), these results do not speak to the issue of causality; a plausible interpretation is that, in fixing the short-term interest rate, each central bank endogenously provided whatever volume of currency and reserves the public and the banks demanded. These results therefore suggest a potential role for the monetary base as an indicator, or information variable, with respect to future economic activity, though not necessarily as a policy instrument.[17] (It is also unclear in this work whether the information

[15] Bernanke and Blinder (1988) had earlier offered a model in which some quantitative measure of monetary policy played a role in the IS curve. But there the point was to incorporate an additional effect associated with credit markets and lending conditions, not the demand for deposit money.

[16] Nelson's empirical work followed an earlier paper by Meltzer (2001).

[17] Although the concept is much older, the basic notion of an indicator or information variable in this context is Tobin's (1970) "post hoc ergo propter hoc" argument (which actually argued against concluding that whatever was "post hoc" was therefore "propter hoc"). See also Brunner and Meltzer (1964) and Friedman (1975).

about future output contained in the monetary base is contained in other variables that are often standard in similar macroeconomic analyses—most obviously, prices and inflation.)

Two further, more recent efforts to explore the information content of monetary aggregates, one associated with the Swiss National Bank (which continued to target money growth until 2000) and the other with the European Central Bank (which at the time of writing still has its monetary "pillar"), also bear mention. In a series of papers, Assenmacher-Weche and Gerlach (2006a, 2006b, _______) showed that for each of the Euro area, Japan, Switzerland, the U.K. and the U.S., money growth and inflation are related at low frequencies like ___________ (and, moreover, for most of these economies, the relationship is one-for-one), after taking into account the influence of interest rates on demand for money. They did not establish, however, how monetary policy can, or should, exploit these low-frequency relationships. By contrast, Fischer et al. (2008) showed for the Euro area that, at the higher frequencies at which central banks commonly make monetary policy decisions, inflation forecasting models based on Euro M3 are less successful than naive or random walk models, while combining M3-based models with the output of the bank's broader macroeconomic analysis delivers forecasts that are superior on some criteria though not on others.

None of these analyses, however, either overturns the essential fact that in recent years central banks have conducted monetary policy by setting short-term interest rates or addresses the fundamental issue that Wicksell (and, implicitly, McCallum) posed. If the central bank's ability to control the interest rate that is the focus of its implementation of monetary policy is due to its control over the supply of its own liabilities, and if the designated interest rate is the relative price associated with an asset that is substitutable for other assets that the public holds—at least in principle, including real capital—then the relationship between the chosen interest rate level and the marginal product of capital bears implications both for the evolution of the economy's price level (because of the unique role played by the central bank's liabilities) and for the asset substitutions and trading that the public undertakes.

Although the primary focus of Wicksell's argument was the implication for prices, it is clear that such arbitrage-like substitutions—in modern language, holding debt instruments versus holding claims to real capital, holding one debt instrument versus any other, holding either debt or equity assets financed by borrowing—were at the heart of his theory. If the interest rate that banks were charging departed from what was available from "investing your capital in some industrial enterprise ... after due allowance for risk," he argued, the nonbank public would respond accordingly; and it was the aggregate of those responses that produced the cumulative movement in the price level that he emphasized. As Wicksell further recognized, this chain of asset-liability substitution would also either deplete or free up banks' reserves. With an interest rate below the "normal rate," the public would borrow from banks and (with rising prices) hold greater money balances; "in consequence, the bank reserves will melt away while the amount of their liabilities very likely has increased, which will force them to raise their rate of interest."

In the world of the gold standard, in which he was writing, it went without saying that this depletion of banks' reserves would cause them to raise their interest rates from whatever they were charging—hence Wicksell's presumption that interest rates, in fact, could and therefore would not remain below the "normal rate." (His theory of the consequences of such a departure, he noted at the outset, "cannot be proved directly by experience because the fact required in its hypothesis never happens.") In a fiat money system regulated by a central bank, however, where the decision makers setting the relevant interest rate are not the bankers but officials of the economy's monetary authority, the central bank's ability to replenish banks' reserves creates just that possibility. This difference does not bear on Wicksell's basic point about cumulative movements in prices; under a fiat money system too, as long as the central bank holds the interest rate below "normal" by continually providing banks with more reserves, the price level will continue to rise. It merely serves to place the basic Wicksell story in a setting of modern central banking, and to indicate how departures of actual interest rates from "normal" in that setting can exhibit greater persistence than he envisioned.

At the same time, drawing out these further aspects of how Wicksell's cumulative price movement comes about highlights two further implications. First, the central bank's ability to maintain a market interest rate different from the "normal rate" depends on the provision of incremental reserves to the banking system. Unless there is reason to think that the "normal rate" (to recall, anchored in the economy's marginal product of capital) is changing each time the central bank changes the market rate—and, further, that all policymakers are doing is tracking those independently originating changes—then there is a counterpart to the central bank's interest rate policy in the quantity of at least some component of its liabilities. Second, because the central bank does not normally hold claims to real capital, the cumulative process triggered by whatever policy-induced departures of its policy interest rate from the "normal" do occur will involve arbitrage-like asset and asset-liability substitutions by the banks and the nonbank public. In this respect too, monetary policy, even when formulated and carried out entirely in terms of interest rates, has a counterpart in quantity movements that are, at least in principle, observable.

3. The Traditional Understanding of "How They Do That"

The traditional account of how central banks go about setting a short-term interest rate—the staple of generations of "money and banking" textbooks—revolves around the principle of supply-demand equilibrium in the market for bank reserves. As depicted in the familiar Figure 3.1, a change in reserve supply leads to a movement along a presumably downward-sloping reserve demand schedule, resulting in a new equilibrium with a larger (or smaller) reserve quantity and a lower (or higher) market interest rate for the asset assumed to be banks' closest substitute for reserves.[18] What is straightforward in this conception is that the reserves held by banks, on deposit at the central bank (or, in some countries' banking system, also in the form of currency), are a liability of the central bank, and that the central bank has a monopoly over the supply of its own liabilities and hence can change that supply as it sees fit. What is less obvious, and in many cases highly specific to the details of individual countries' banking systems, is why banks hold these central bank liabilities as assets in the first place, and why banks' demand for them is negatively interest elastic.

The demand for reserves.

Four rationales have dominated the literature on banks' demand for reserves. First, in some countries (the United States, for example), banks are required to hold reserves at the central bank at least in stated proportions to the amounts of some or all kinds of their outstanding deposits.[19]

[18] This simplified diagram abstracts from Lombard-style lending facilities, and the payment of interest on excess reserves, both of which are common among major central banks.

[19] As of 2009, reserve requirements in the United States were 3 percent on net transactions balances in excess of $10.3 million and up to $44.4 million (for an individual bank), and 10 percent on transactions balances in excess of $44.4 million. The reserve requirement was 0 on both non-personal time deposits and eurocurrency liabilities, regardless of amount. Personal time deposits are, by law, exempt from reserve requirements. Among the large western

Second, banks' role in the payments mechanism regularly requires them to execute interbank transactions, and transfers of reserves held at the central bank are often the most convenient way of doing so. In some countries (Canada, for example), banks are not explicitly required to hold any specific amount or proportion of reserves at the central bank but they are required to settle certain kinds of transactions via transfers of such reserves.[20] In some countries (again, the United States, for example), banks enter into explicit contracts with the central bank specifying the quantity of reserves that they will hold, at a minimum, in exchange for the central bank's provision of settlement services. Third, banks also need to be able to satisfy their customers' routine demands for currency. In the United States, the currency that banks hold is included in their reserves for purposes of satisfying reserve requirements, and many banks' currency holdings are more than sufficient to meet their reserve requirements in full.[21] Fourth, because the prospect of the central bank's defaulting on its liabilities is normally remote, banks may choose to hold reserves (deposits at the central bank and conceivably currency as well) as a nominally risk-free asset. Because other available assets are very close to being riskless in nominal terms, however, and because some of those other assets typically bear returns in excess of the return that banks earn from holding reserves, it is not obvious that this rationale accounts for any significant amount of banks' actual demand for reserves, at least not in economies with well developed financial markets.

Under each of these four reasons for banks to hold reserves, the resulting demand, for a given interest rate (perhaps zero, as on currency) credited on reserve balances, is plausibly elastic

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economies, the United States is highly unusual in having reserve requirements in the 21st century. A sizeable literature has investigate whether reserve requirements are necessary, or even useful, in inducing banks to hold reserves at the central bank; see, for example, _________________.

[20] [footnote, analogous to the preceding one, with some specifics of the Canadian rules to this effect]

[21] Usually, under these arrangement the currency held by banks is correspondingly excluded from standard measures of currency in circulation.

with respect to interest rates on other assets that banks could hold instead. With stochastic deposit flows and asymmetric costs of ending up over- versus under-satisfying the applicable reserve requirement (which takes the form of a weak inequality), a bank optimally aims, in expectation, to over-satisfy the requirement. But the margin by which it is optimal to do so clearly depends on the differential between the interest that the bank would earn on those alternative asset and the interest paid on its reserve holdings. Standard models of optimal inventory behavior analogously imply negative interest elasticity for a bank's holding of clearing balances to use for settling a stochastic flow of interbank transactions, and for its holdings of currency to satisfy customers' stochastic currency needs. Standard models of optimal portfolio behavior similarly render the demand for risk-free assets negatively elastic to the expected excess return on either the market portfolio of risky assets or, in a multi-factor model, the expected excess return on the one risky asset that is most closely substitutable for the risk-free asset.

Monetary policy and asset market equilibrium

One way to formalize the relationship between interest rates and reserves is through a system of asset demand equations. We can think of banks as choosing between three alternative assets: reserves (*R*), federal funds (*F*), and Treasury securities (*T*). In matrix notation, such a system would look like

$$\begin{pmatrix} R \\ F \\ T \end{pmatrix}_t^d = \alpha + \mathbf{Br} = \begin{pmatrix} \alpha^R \\ \alpha^F \\ \alpha^T \end{pmatrix} + \begin{pmatrix} \beta^{RR} & -\beta^{RF} & -\beta^{RT} \\ -\beta^{FR} & \beta^{FF} & -\beta^{FT} \\ -\beta^{TR} & -\beta^{TF} & \beta^{TT} \end{pmatrix} \begin{pmatrix} r^R \\ r^F \\ r^T \end{pmatrix}_t . \qquad (3\text{-}1)$$

Othershave shown how a linear demand system of this form can be derived from the maximization of expected utility, in which the **B** matrix is a function of the covariance matrix of returns and the coefficient of relative risk aversion.[22]

As discussed above, the tradeoff relevant for reserve demand is between the return on reserves (zero) and those on alternative assets (in this case, federal funds and Treasuries).

[22] See and Friedman and Roley (1987).

Ceteris paribus, the demand of reserves would be reduced by either a rise in the loan rate or a fall in the rate of return on reserves. This implies a downward-sloping reserve demand curve as a function of Treasury and fed funds rates.

Working with a three-asset system is cumbersome, but the structure of the reserves market suggests some simplifications. Dropping the Treasury equation and assume $r^R = 0$ without loss of generality leaves two equations for reserves and fed funds demand,

$$R_t^d = \alpha^R - \beta^{RF} r_t^F - \beta^{RT} r_t^T + e_t^R \tag{3-2}$$

$$F_t^d = \alpha^F + \beta^{FF} r_t^F - \beta^{FT} r_t^T, \tag{3-3}$$

with a reserve demand shock, e^R appended to the reserve demand equation. Fed funds are in zero net supply, so we will set $F = 0$.

While it is often assumed that the Fed supplies a fixed quantity of reserves, as depicted in Figure 3.1, we will allow the Fed to provide reserves according to

$$R_t^s = R^* + \Theta(r_t^F - \bar{r}^F), \tag{3-4}$$

where

$$R^* = \alpha^R - \beta^{RT}\alpha^F - \bar{r}^F[\beta^{RF} + \beta^{RT}(\beta^{FT})^{-1}\beta^{FF}]. \tag{3-5}$$

We can now equate reserve supply with demand and solve for r^F,

$$r_t^F = \frac{\Theta\bar{r}^F + \alpha^R - \beta^{RT}\alpha^F - R^* + e_t^R}{\Theta + \beta^{RF} + \beta^{RT}(\beta^{FT})^{-1}\beta^{FF}}. \tag{3-6}$$

With R^S equal to the R^* given in equation 3-5, $r^F = \bar{r}^F$ in the absence of a reserve demand shock.

Not surprisingly, the result is a reserve supply schedule that is upward sloping in (R, r^F) space, with slope $1/\Theta$. Reserve demand is a downward-sloping line with slope $1/-\beta^{RF}$. When $R^s = R^*$ and in the absence of any shocks, the intersection of reserve supply and demand occurs at the target funds rate.

The stylized three-equation demand system illustrates several important points concerning the traditional view of monetary policy implementation. First, in the absence of a reserve demand shock, it doesn't matter whether Θ is large or small. If the Desk chooses the correct R^*, then the funds rate will equal its target in equilibrium. Second, if there is a reserve demand shock, then Θ will determine the degree to which the shock affects the equilibrium funds rate (a larger Θ implies a smaller effect).

Third, suppose reserve demand were "decoupled" from other financial markets in the sense that $\beta^{RF} = \beta^{RT} = 0$. This corresponds to a vertical reserve demand schedule, and in this case $R^* = \alpha^R$. If $\Theta > 0$ so that the reserve supply schedule is upward sloping, then the equilibrium funds rate will equal its target. If this were true, the Fed would be able to effect changes in the equilibrium funds rate without changing the quantity of reserves. The Fed simply changes the value of $\bar{r}^F$ in its supply equation, and announces its willingness to "enforce" that target by changing reserves. In principle, it doesn't matter whether Θ is large or small. But even when the fed funds market is decoupled in this way, changes in the equilibrium funds rate (brought about by changes in the announced $\bar{r}^F$) *will* lead to changes in the Treasury rate. What makes this work is substitution between fed funds and Treasuries, and this depends on β^{FT}, *not* on β^{RF} and β^{RT}.

The "liquidity effect"

An immediate implication of the model sketched above (and the even more basic idea represented in Figure 3.1) is that increases in the supply of reserves, instigated independently by the central bank, will cause the federal finds rate—and, except in special cases of non-substitutability, other interest rates as well—to fall: the so-called "liquidity effect." Beginning in the early 1990s, an extended empirical literature sought not only to document a negatively interest elastic reserve demand but also to find evidence that changes in reserve supply systematically resulted in movements in some relevant short-term interest rate. Evidence for such an effect has been difficult to establish, however. Moreover, since the early 1990s what evidence there was has become substantially weaker.

Using simple mechanical distributed lag models relating the monthly federal funds rate to the growth of the monetary base, Leeper and Gordon (1992) were able to replicate the kind of negative relationships sometimes construed as evidence for such an effect.[23] Their results were fragile, however: The negative correlation appeared only if such variables as output and prices, and even lagged interest rates, were excluded from the estimated regressions; efforts to isolate an affect associated with the unanticipated component of monetary base growth showed either no correlation or even a positive one; and their findings differed sharply across different subperiods of the 1954-90 sample that they examined.

Strongin (1995) subsequently argued that the failure of previous attempts to provide evidence for the "liquidity effect" of monetary policy actions on interest rates (as well as the absence of a significant effect on variables like output, which are not the focus of concern in this chapter) was due to an underlying failure to identify monetary policy actions themselves. When the central bank is fixing a short-term interest rate at some given level, part of the movement in the supply of reserves—arguably a very large part—reflects the attempt to accommodate random variation in reserve demand designed to keep the chosen interest rate from changing, not an independent movement in reserve supply intended to change it. Hence simply using a regression with the interest rate as dependent variable and a measure of reserves as an independent variable is problematic.

By assuming that the quantity of total reserves varies mostly as a result of the Federal Reserve's attempt to accommodate shocks to reserve demand, while policy actions intended to move the interest rate are reflected in the mix between borrowed and nonborrowed reserves, Strongin extracted a measure of monetary policy actions that he showed to be empirically associated with the theoretically expected interest rate response: a falling interest rate in response

[23] A prior literature had focused on the relationship between interest rates and measures of deposit money like M1 and M2, but especially over short horizons it is not plausible to identify movements of these "inside" monetary aggregates with central bank policy actions. See Thornton (1988) and Pagan and Robertson (1995) for reviews of this earlier literature.

to an expansionary policy intervention.[24] (The estimated response of output was consistent with the standard theory as well.) Further, these results were robust across subperiods within the 1959-92 sample. The estimated interest rate response was small, however: within the month, a decline (increase) of only 7 basis points in response to an 1 percent increase (decrease) in reserves—or about $400 million.

Pagan and Robertson (1995) likewise argued that the principle difficulty with the existing empirical literature was the failure to take adequate account of the system-wide interactions, in the first instance between factors (like monetary policy) affecting the money (or reserves) supply and money demand, but more broadly including the interaction of money, interest rate, output and prices. The emphasis in their contribution was therefore on the choices to be made in restricting the vector autoregressive representation of such a system of presumably but nonetheless unspecified underlying structural relationships. By applying a large set of restrictions across systems of equations for variables like the quantity of nonborrowed reserves (or the monetary base), interest rates, industrial production, consumer prices, exchange rates, and commodity prices, estimated with monthly data for 1974-93, they were able to establish an economically significant impact of the estimated independent component of either reserves or the base changes on the short-term interest rate. With fewer restrictions, however, the estimated effect was smaller, of the same magnitude as found in simple single-equation models. Further, the results varied sharply across halves of the sample period (with weaker estimated effects in the latter half of the sample). The most important aspect of this work, for purposes of this chapter, is again the finding of only a small and weakly established effect on short-term interest rates due to movements in the quantity of reserves or the monetary base. In the model that they take to be most representative, for example, a 1 percent change in nonborrowed reserves results

[24] The focus on the mix between borrowed and nonborrowed reserves was consistent with the Federal Reserve's own discussion of a "borrowed reserves" operating strategy for targeting the federal funds rate following the collapse of the central role of monetary aggregates in 1982.

in an estimated impact of only 13 basis points. As they explicitly pointed out, these findings, if taken at face value, imply that most of the variation in the federal funds rate is in fact not due to any action by the central bank.

Bernanke and Mihov (1998), more closely following Strongin, used a vector-autoregression model to identify a measure of independent monetary policy innovations that allowed not only for the endogenous policy response to changing economic conditions but also for potential changes over time in the Federal Reserve's operating procedures. The "semi-structural" VAR that they used left the relationships among the model's macroeconomic variables unrestricted, but imposed contemporaneous identification restrictions on those variables directly relevant to the market for bank reserves (total reserves, reserve borrowings, nonborrowed reserves, the discount rate and the federal funds rate). Using both monthly and biweekly data for 1965-96, they found that the Federal Reserve normally varied reserve supply so as to accommodate disturbances to reserve demand—and as is consistent with a policy procedure aimed at fixing an interest rate (and also corresponding to the reason for not simply taking the supply of reserves as exogenous in the first place).[25] In contrast to earlier work, they also found a sizeable liquidity effect: in the biweekly model, an increase (decrease) in the federal funds rate of approximately 100 basis points in response to an independent 1 percent decrease (increase) in the supply of nonborrowed reserves.

In an influential series of papers, Christiano and Eichenbaum (1992, 1995) and Christiano Eichenbaum and Evans (1996a, 1996b) considered several different quantity variables and methods for discerning monetary policy shocks from structural VAR. Their principal conclusion, as summarized in Christiano et al. (1997), was that in the end, the VAR

[25] Bernanke and Mihov also estimated the model over various subperiods within the 1965-96 sample, and they employed Hamilton's (1989) switching technique to look for points of regime change. The principal finding from this analysis was that during the 1979-82 "monetarist" experiment the accommodation of disturbances to reserve demand was approximately zero.

identification scheme was less important than the choice of quantity variable. In the 1965Q3 to 1995Q2 sample, they found that shocks to nonborrowed reserves generated a liquidity effect, and that this result was largely robust to alternative identifying assumptions. Broader aggregates, such as the monetary base or M1, failed to do so.

Hamilton (1996, 1997) adopted a different approach to empirically investigating the liquidity effect, using daily data and taking careful account of such institutional features as the Federal Reserve's two-week "reserve maintenance" period (banks must meet their reserve requirements not on a daily basis but on average over two consecutive weeks). Using data from March 1984 to November 1990, Hamilton (1996) found evidence of imperfect substitutability of banks' demand for reserves within the two-week maintenance period, inferring from this some scope for the Fed to exploit the liquidity effect to manipulate the funds rate. In a related paper, Hamilton (1997) used the Desk's reserve targeting errors to estimate the funds rate response to exogenous reserve changes, and concluded that the liquidity effect was sizeable: a $300 million decrease (increase) in nonborrowed reserves would, if sustained over the entire maintenance period, lead to a 100 basis point increase (decrease) in the funds rate.

Finally, it is important to point out that in recent years even methodologies like that of Strongin, Bernanke-Mihov and Christiano-Eichenbaum-Evans, that in the past indicated sizeable movements of interest rates in response to changes in one or another measure of reserve supply, now no longer do so. The top two panels of Figure 3.2 show impulse response functions for the federal funds rate from a VAR estimated using monthly data spanning 1982-93. The system represented in the top panel includes the volume of deposits in the U.S. banking system, the interest rate and nonborrowed reserves. Although the estimate effect on the interest rate of a sustained one standard deviation increase in nonborrowed reserves is not large, it is statistically significant and it does persist for about a half a year. An analogous VAR but with the monetary base in place of nonborrowed reserves, shown in the middle panel, indicates no significant impact on the interest rate even for the same 1982-93 sample. By contrast, as the bottom panel shows, for the 1994-2007 sample even the system estimated for nonborrowed reserves shows no significant interest rate impact.

Evidence for an interest-elastic reserve demand

An even prior question, however, is whether there is evidence to support the concept of a negatively interest elastic demand for reserves, corresponding to equation 3-2. For the United States today, the answer is yes—but only if the relevant measure of reserves is taken to include banks' contractually held clearing balances.[26] As Figure 3.3 shows, contractual clearing balances have become increasingly important since they were introduced in the early 1990s. In parallel, borrowed reserves have become far less important.[27] From 1975 through 1989 (top panel), the difference between total reserves and nonborrowed reserves is clearly visible, and clearly varying over time. Since 1990 (bottom panel), total reserves and nonborrowed reserves have become virtually indistinguishable, while contractual clearing balances have grown to about $10 billion.

Column 1 of Table 3.1 shows the results of estimating a reserve demand equation of the form

$$R_t = b_0 + b_1\bar{r}_t^F + b_2\bar{r}_{t-1}^F + b_3R_{t-1} + b_4RR_t + \mathbf{cX}_t + u_t \qquad (3\text{-}7)$$

where *R* is U.S. banks' holdings of excess reserves (that is, reserves in excess of the required minimum) plus contractual clearing balances; $\bar{r}_t^F$ is the federal funds rate targeted by the federal Reserve System; **X** is a vector of measures of actual and potential bank payments volume: demand deposits outstanding, other checkable deposits outstanding, the dollar volume of

[26] See Stevens (1993) for a description of clearing balances. Sellon and Weiner (1996) suggested that banks' clearing balances were likely to replace conventional reserves measures as the fulcrum of monetary policy.

[27] Hence Hanes's (2004) apt reference to "the disappearance of the borrowing function in the United States."

Fedwire transactions,[28] and the number of Fedwire transactions; *RR* is banks' required reserves for the period; all quantity variables are in logarithms; and the regression also includes an intercept as well as dummy variables for December 1999 and January 2000 (to allow for unusual patterns of reserve demand in anticipation of the potential "Y2K problem"). The b_1 coefficient in the regression equation 3-7 corresponds to the β^{RF} in equation 3-2. The equation is estimated by ordinary least squares, using monthly data spanning January 1994 to June 2007.[29]

The estimated long-run interest elasticity is –0.095, and it is statistically significant at the 1% level. It is also economically significant: it means that, on average, a 100 basis point increase in the federal funds rate reduces banks' demand for excess reserves plus clearing balances by 9.5 percent, or about $950 million given the normal quantity of approximately $10 billion held. The coefficient of 0.779 on the lagged dependent variable, together with the pattern of coefficients on the two interest rate terms, implies a gradual adjustment that is half-complete after roughly three months—a plausible finding in light of most banks' practice of renegotiating their contractual clearing balances only about once per quarter (and not in a coordinated way among individual banks).[30] The coefficients on the variables measuring the actual and potential volume of bank payments are mostly not statistically significant, but this is hardly surprising in light of their mutual correlation. The required reserves variable per se is not significant.

These results do not carry over, however, to measure of reserves that do not include contractual clearing balances. As the next column of Table 3.1 shows, analogous estimates for excess reserves alone indicate a long-run interest elasticity of –0.025 (a demand reduction of $35

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[28] The monthly dollar volume of Fedwire transactions is interpolated from the Federal Reserve's published quarterly series. Monthly data are not publicly available.

[29] Fedwire transactions data are available beginning in 1994. The sample ends at mid 2007 is intended to exclude the period of stress in the banking system associated with the 2007-? financial crisis. Analogous results for regressions including an AR(1) correction rather than the dependent variable are roughly comparable.

[30] See ___________________________.

million for a 100 basis point increase in the interest rate, at the sample average excess reserves quantity), but the value is only marginally significant statistically. It is immediately clear from Figure 3.4 how this contrast, in both magnitude and statistical significance, arises. In the top panel, the negative relationship between the federal funds rate and the sum of excess reserves plus contractual clearing balances is readily visible. No such relationship is visible between the interest rate and excess reserves alone in the bottom panel.

The remaining columns of Table 3.1 show a similar lack of interest elasticity for other familiar reserve measures that do not include contractual clearing balances. Nonborrowed reserves exhibit a long-run interest elasticity of only –0.0017 (but corresponding to a demand reduction of $78 million for a 100 basis point increase in the interest rate, given the much larger nonborrowed reserves quantity), and marginally significant statistically. Oddly, for total reserves (nonborrowed reserves plus banks' borrowings from the Federal Reserve, or, equivalently, excess reserves plus required reserves) the estimated long-run interest elasticity is positive.

Challenges to the Traditional View

Especially since banks adjust their contractual clearing balances only slowly over time, the absence of a significant negative observed interest elasticity for measures of reserve demand that exclude these clearing balances only further compound the puzzle presented by the failure of the "liquidity effect" literature to find a significant response of interest rates to changes in reserve supply. If reserve demand really is interest inelastic, or nearly so, then even very small changes in reserve supply should be sufficient to bring about sizeable movements in short-term interest rates—which, in fact, seems to be the case (the findings of the liquidity effect literature notwithstanding).

A further long-standing question in this literature is how these small movements of reserve supply suffice to change the interest rates on other assets that exist and trade in far larger volume. Compared to the roughly $50 billion of reserves that banks normally hold in the United

States, or $60 billion in reserves plus contractual clearing balances, the outstanding volume of security repurchase agreements is normally more than $1 *trillion*. The volume of U.S. Treasury securities due within one year is likewise normally over $1 *trillion*. And so too is the volume of commercial paper (even after the shrinkage during the recent financial crisis). As Figure 3.5 shows, the small changes in reserve supply that move the federal funds rate move the interest rates on these short-term instruments as well.

The conventional answer, following Brainard and Tobin (1963), is that what matters for this purpose is not the magnitude of the change in reserve supply but the tightness of the relationships underlying reserve demand.[31] In a model in which banks' demand for reserves results from reserve requirements, for example, a 10 percent requirement that is loosely enforced, and that applies to only a limited subset of banks' liabilities, would give the central bank less control over not only the size of banks' balance sheets but also the relevant market interest rates not only on federal funds but on other short-term assets too than a 1/10 percent requirement that is tightly enforced and that applies to all liabilities that banks issue. In a model also including nonbank lenders, the central bank's control over the relevant interest rate is similarly impaired by borrowers' ability to substitute nonbank credit for bank loans.

The mechanism that "amplifies" the effect of what may be only small changes in reserve supply, so that they determine interest rates in perhaps very large markets, therefore rests on the tightness of the connection, or "coupling," between reserve demand and the demands for and supplies of other assets. A further aspect of the literature of this subject in recent years, therefore, is whether, and if so to what extent, changes in market institutions (due to legal and regulatory developments, for example) and in the range and ease of market participants'

[31] The point is made more explicitly in the "money multiplier" example given in Brainard (1967).

transaction capabilities (due to advances in electronic communications and data processing, for example) have eroded the tightness of this "coupling."

4. A More Satisfactory Understanding of "How They Do That"

Either the finding that reserve demand is interest inelastic, *or* the observation that little or no change in reserve supply is needed to move the federal funds rate even if reserve demand is elastic, presents a significant challenge to the traditional view of how central banks set interest rates as represented in Figure 3.1. If reserve demand is interest inelastic, then not just each individual bank but the market as a whole is, in effect, a price taker in the market for bank reserves. In that case one can represent the central bank as supplying reserves perfectly elastically, as in the left-hand panel of Figure 4.1, or with some upward-sloping interest elasticity as in the right-hand panel; but with an inelastic reserve demand the difference is not observable. Either way, the central bank is, in effect, simply choosing a point on a vertical demand schedule, and the only remaining question is how it communicates to the market which point it has chosen.

By contrast, if the demand for reserves is interest elastic, as it seems to be at least when the reserve measure includes contractual clearing balances, then for the central bank to be able to move the relevant market interest rate without changing the supply of reserves (or with a change smaller that what the demand elasticity implies) requires that the demand schedule shift, as shown in Figure 4.2. From the perspective of achieving the change in interest rates that the central bank seeks, a *shift of* the demand schedule takes the place of the traditionally conceived *movement along* the demand schedule pictured in Figure 3.1.

What would cause the reserve demand schedule to shift in this way? A class of explanation that is familiar in other asset demand contexts turns on expectations of future asset returns. A bank investor deciding between making a loan at *X* percent and holding a Treasury bill at *Y* percent might decide differently depending on whether or not the rate on loans of that risk category were expected to remain at *X* percent for the foreseeable future. The expectation of an imminent increase to some higher (lower) rate would make then bank less (more) eager to extend the loan now, and therefore more (less) eager to hold the Treasury bill and wait to make the loan after the rate had risen. Hence the bank's willingness to lend, for given interest rates, would have *shifted*.

Extending this logic to one-day loans is problematic. If today the overnight federal funds rate is *X* percent and the Treasury bill rate *Y* percent, the expectation that the overnight rate is going to be different from *X* percent in the future does not directly affect a bank's willingness to lend in the federal funds market today. The reason is that there is no substitution opportunity between a one-day loan in the future and a one-day loan today. In principle, the usual logic of "term structure" arbitrage does not apply.

A feature of the reserve market that the existing empirical literature has emphasized, however, is that over very short time horizons the required reserve accounting procedures in effect in the United States, Japan, and some other countries create exactly this kind of "term structure" arbitrage possibility. In the United States, for example, what matters for a bank's meeting its reserve requirements is its holdings of reserves *on average* over a two-week reserve maintenance period. Apart from risk factors, such as the possibility of not being able to borrow in the federal funds market on some future day, a bank therefore does have an incentive to arbitrage holding its reserves today versus holding them at some future day within the maintenance period. Wholly apart from any expectation of changes in the rates on other assets, the expectation that the federal funds rate will be lower (higher) on some future day within the maintenance period reduces (increases) the bank's willingness to borrow reserves *at a given federal funds rate* in order to hold them today. The expectation of a future rate change therefore shifts the demand for reserves today. For countries whose banking systems operate under this kind of multi-day reserve-maintenance-period system, the literature analyzing the link between interest rates and reserves has frequently emphasized this kind of "anticipation effect."[32]

Two questions remain, however. First, where would these anticipations of a future change in the federal funds rate come from? Since the interest rate whose future movements are being anticipated is one that the central bank sets, or at least targets, one immediate possibility is indications of intent originating from the central bank itself. Most obviously, the central bank could simply announce its intention to raise or lower the relevant interest rate in the future. If it credibly did so—and if the change were announced for a time in the future but nonetheless within the current maintenance period—its announcement would create an arbitrage incentive such that the interest rate would immediately go to that level unless the central bank acted to resist this movement. But the same logic applies to any anticipation of a forthcoming interest rate change, whether based on a central bank announcement or not, as long as it is expected to take place within the current maintenance period.[33]

The further, and more significant question is what analog to this process might apply over horizons that are of greater interest for purposes of macroeconomic analysis of monetary policy. The fact that the central bank can move its policy interest rate via an "anticipation effect" (or even an "announcement effect") that shifts the prevailing reserve demand schedule, and therefore without having to implement any change in reserve supply, over a matter of a few days, or at most a few weeks, would not matter much in a macroeconomic context. Once the reserve maintenance period ended, the logic accounting for the shift in reserve demand (as in Figure 4.2)

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[32] See, for example, ____.

[33] Indeed, for the United States thee is substantial evidence that the Federal Reserve systematically acts to resist just such tendencies, based not on its announcements (the Federal Reserve's announcements of interest rate changes are effective immediately) but on market expectations of forthcoming monetary policy decisions.

would no longer apply and only by changing reserve supply (as in Figure 3.1) could the central bank keep the interest rate from reverting to its prior level.

The Anticipation and the Announcement Effects

In the very short run, therefore—that is, within the reserve maintenance period—banks' reserve demand will also depend on *today*'s effective funds rate relative to the rate that's expected to prevail within subsequent days of the period. We can incorporate this into our framework by adding to equation 3-2 a term involving the difference between the time *t* effective fed funds rate and the expected future rate, $E_t r_{t+1}^F$

$$R_t^d = \alpha^R - \beta^{RF} r_t^F - \beta^{RT} r_t^T - \gamma(r_t^F - E_t r_{t+1}^F) + e_t^R \quad (4\text{-}1)$$

Here we have characterized the intra maintenance period substitution in terms of the current and next day's expected funds rate. Things are more complicated than that in practice, however. For one thing, banks can substitute across all days in the reserve maintenance period, and so there will be terms involving other days within the period. Furthermore, the degree of substitutability is affected by complex features of the Fed's reserve accounting system, such as carryover provisions and daylight overdraft fees. Detailed analyses of banks' within maintenance period optimization problem have been performed by Clouse and Dow (2002), Bartolini et al. (2002) and Furfine (2000). Although it is highly stylized, equation 4-1 broadly resembles these models' solutions in its incorporation of the expected future interest ratte.

On the supply side, we assume

$$R_t^s = R^* + \lambda\gamma(E_t r_{t+1}^F - \bar{r}_t^f) + u_t^R \quad (4\text{-}2)$$

where $\bar{r}^F$ again represents the funds rate target, $E_t r_{t+1}^F$ is tomorrow's expected funds rate, and R^* is the level of reserves consistent with $r^F = \bar{r}^F$ in the absence of any shocks or expected changes in the funds rate target.[34] A reserve supply shock, u_t^R, is included representing exogenous factors affecting the level of reserves, such as fluctuations in Treasury balances.

[34] To simplify the algebra we will ignore the $\beta^{RT} r_t^T$ term from the reserve demand equation, which simplifies equation 3-5 to $R^* = \alpha^R - \bar{r}^F \beta^{RF}$.

Parameterized in this way, the λ represents the degree to which the Desk allows the expected future funds rate to affect today's rate. In the $\lambda = 0$ polar case, the Desk is passive, and makes no effort to prevent changes in $E_t r_{t+1}^F$ from affecting the effective funds rate. In the $\lambda = 1$ polar case, the Desk adds or drain reserves in sufficient quantity to hold the effective funds rate at $\bar{r}^F$, regardless of expectations. Note that this differs from the earlier *inter*-maintenance day analysis, where we were assuming the Desk supplied whatever volume of reserves was needed to hit the target.

Equating supply with demand gives

$$\lambda\gamma(E_t r_{t+1}^F - \bar{r}^F) + u_t^R = -\beta^{RF} r_t^F - \gamma(r_t^F - E_t r_{t+s}^F) + e_t^R \tag{4-3}$$

and solving for the equilibrium funds rate yields,

$$r_t^F = \frac{\beta^{RF} + \lambda\gamma}{\beta^{RF} + \gamma}\bar{r}^F + \frac{(1-\lambda)\gamma}{\beta^{RF} + \gamma}E_t \bar{r}_{t+1}^F + \frac{1}{\beta^{RF} + \gamma}(e_t^R - u_t^R) \tag{4-4}$$

The funds rate delivered by the desk will therefore be a convex combination of the target rate and the expected rate, plus a term involving the supply and demand shocks.

The equilibrium condition 4-4 has a number of important implications for the implementation of monetary policy in the very short term. One is that the equilibrium funds rate is a linear combination of the target and the expected future (but within maintenance period) rate. The larger the γ the stronger the "anticipation effect; a larger value of α (more "leaning against the wind") weakens this effect.

Second, it is plausible to assume that within a maintenance period, the β^{RF} coefficient is zero, or nearly so, as is the β^{RT} coefficient we had dropped earlier. Instead, the bank's decision is really all about rearranging reserve balances within the maintenance period in order to minimize the cost of holding those balances. If this is true, then we can see from equation 4-3 that $r_r = E_t r_{t+s}^F = \bar{r}^F$ is an equilibrium in the absence of any shocks. So in the case of a "decoupled" reserves market (in the sense that the desired level of reserves is insensitive to the level of the funds rate), convincing market participants that the funds rate was going to equal $\bar{r}^F$ would move the equilibrium to $\bar{r}^F$ without a need for any open market operations. (In graphical terms, changes in the expected funds rate shift reserve supply and demand by equal amounts.) This is one way to represent the "announcement effect" as it applies at this very short run context.

Third, the impact of shocks to reserve demand or supply is $1/(\gamma + \beta^{RF})$, which will be smaller than $1/\beta^{RF}$ to the extent that $\gamma > 0$.

Fourth, late in the maintenance period—and especially on the final day—there is less (no) scope for substitution from one day to the next: γ shrinks, becoming zero on settlement Wednesday.[35] With the anticipation effect weakening, the funds rate converges to the target in the absence of shocks. But reserve supply and demand shocks have a larger impact on the equilibrium funds rate, as the end of the maintenance period approaches, which explains the unusually large funds rate volatility typically associated with settlement Wednesday.

Finally, while $E_t\bar{r}^F_{t+1}$ is not strictly exogenous, equation 4-4 can be solved forward to obtain the current funds rate as a function of the expected future target rate. Announcements signaling a change in the future funds rate target will cause the current funds rate to jump and subsequently convergence over time to the new target.[36]

Supply and demand within the maintenance period

The goals of this section are threefold. The first is to corroborate the "liquidity" and "anticipation" effects that have been documented by Hamilton (1997) and Carpenter and Demiralp (2002). The second is to determine the sensitivity of reserve demand to the *level* of the Fed funds rate at this very high frequency. If the elasticity of reserve demand is very small (zero), then the Desk can effect funds rate changes with very small (no) changes in reserves. The third objective is to characterize the Desk's reserve supply function, and in particular to determine the degree to which the Desk responds to deviations of the funds rate from its target as opposed to the *level* of the funds rate. The latter will give us an estimate of how much the Desk changes reserves in order to change the funds rate.

[35] US banks are allowed to carry over some amount of reserve balances into the next period, so there *is* a possibility of holding more reserves during this period if a higher rate were expected to prevail in the next.

[36] The dynamics would become more complicated if the cumulative reserve surplus/deficiency were included as a state variable, and the finite 10-day maintenance period makes it an even more complicated problem; see Clouse and Dow (2002).

Reserve demand and the liquidity effect

The starting point for estimating reserve demand and the liquidity effect is equation 4-1,

$$R_t^d = \alpha^R - \beta^{RF} r_t^F - \beta^{RT} r_t^T - \gamma(r_t^F - E_t r_{t+1}^F) + e_t^R .$$

It will be useful to rewrite $r_t^F - E_t r_{t+1}^F$ as the current deviation of the funds rate from its target plus the expected change in the target rate, which assumes that the future effective rate is equal to the target, $r_t^F - \bar{r}_t^F - E_t(\bar{r}_{t+1}^F - \bar{r}_t^F)$. The funds rate deviation can move to the left-hand side of the equation, and dividing through by γ to yield

$$r_t^F - \bar{r}_t^F = \gamma^{-1}\alpha^R - \gamma^{-1}\beta^{RF} r_r^F - \gamma^{-1}\beta^{RT} r_r^T - E_t(\bar{r}_{t+1}^F - \bar{r}_t^F) - \gamma^{-1} R_t - \gamma^{-1} e_t^R .$$

A few adjustments are needed to bring this equation more closely into line with the way the reserves market works. First, reserve demand is subject to a number of calendar effects. For a variety of reasons, reserve demand may vary across days of the maintenance period. (Because of the way the average balance is calculated, for example, balances held on Friday also count for Saturday and Sunday.) Settlement Wednesday has also historically been subject to jumps in reserve demand (less so now under lagged reserve accounting). The same goes for the last day of the month. Also, the volatility of reserve demand fell markedly with the (re-) introduction of lagged reserve accounting on July 20 1998, and as we will see this led to a significant downward shift in reserve demand. A number of dummies will be included in the regression equation to capture these effects.

Second, in a multi-day reserve maintenance period, what matters is not just the next day's expected funds rate. Rather, cost-minimizing banks will look at the rate that's expected to prevail over the remaining days of the days of the period. We therefore need to replace $E_t \bar{r}_{t+1}^F$ with $E_t \bar{r}_{t+s}^F$ in which the *t*+*s* subscript refers to the subsequent days within the maintenance period.

Fortunately, knowing the schedule of FOMC meetings and the maintenance periods, it is possible to use fed funds futures data to calculate futures-based measures of this expectation. Selva and Demiralp did this in their paper, and we do the same. The degree of substitutability across days may vary according to the day of the period, however. On the last day, of course, there will be no scope for substitution.[37] We will therefore allow the coefficient on the expected future funds rate change (the γ^{-1}) to vary across days.

Third, an important factor affecting reserve demand but omitted from the above discussion is the cumulative excess (or deficiency) in the level of reserves relative to required reserves. If for whatever reason a bank accumulates a larger-than-needed level of reserves during previous days of the reserve maintenance period, then that bank will be able to maintain smaller balances on subsequent days. For this reason, we need to include a variable, R_{t-1}^{X}, reflecting the level of excess balances accumulated through the previous day. (Of course this variable is only weakly exogenous, as it reflects the summation of previous days' reserve demand decisions.) Naturally, cumulative excess reserves is by definition equal to zero on the first day of the maintenance period.

Finally, since the funds rate and the Treasury bill rate are in practice very highly correlated, we will include as a regressor only r_t^F; and in fact, because the longer-run portfolio allocation decision (as opposed to the within maintenance period substitution) is surely not driven by day-to-day funds rate fluctuations, we will use the target rate instead of the effective rate, thereby eliminating any correlation between the regressor and the error term.

With these modifications, our regression equation becomes

$$r_t^F - \bar{r}_t^F = \text{dummy terms} - \theta_1 r_t^F - \theta_2 R_t - \theta_3 R_{t-1}^X - \sum_{j=1}^{9} \varphi_j \Delta^e \bar{r}_{t+1}^F + \tilde{e}_t^R \qquad (4\text{-}6)$$

where $\tilde{e}_t^R = \gamma^{-1} e_t^R$. We have all the data we need to estimate this equation. The funds rate and its target are readily available, as are the fed funds futures prices used to construct a measure of the average funds rate expected to prevail over the remaining days of the maintenance period.

An econometric problem inherent in estimating equation 4-6 is that the reserve demand error term, includes a number of demand shifters that are known (or at least anticipated with a reasonable degree of accuracy) by the Desk. Because its operational objective is to achieve a certain target for the funds rate, the Desk will accommodate these shifts through changes in

[37] This is not strictly true in the US, as banks are allowed, up to a limit, to carry over excess reserves from one period to the next. This works only one way, however, as banks may not make up for a deficiency in one period with an excess in the next.

reserves, thus mitigating the shocks' impact on the effective funds rate. Consequently, there is reason to believe that $Cov(R_t e_t^R) > 0$, and one would therefore expect an upward bias in the OLS parameter estimate. In fact, the Fed's tendency to supply additional reserves in response to the upward pressure on the funds rate created a positive reserve demand shock could lead to a spurious *positive* coefficient on R_t. This is precisely what one observes in a regression of the funds rate deviation on either nonborrowed or excess reserves, as shown in the first two columns of Table 4.1.

This is why in their efforts to estimate the "liquidity effect," defined as the impact of a change in reserves on the federal funds rate, Hamilton (1997) and Carpenter and Demiralp (2002) used the reserves "miss"—the difference between the actual and Desk's intended reserve supply—in place of the level of reserves.[38] The solution is to estimate instead

$$r_t^F - \bar{r}_t^F = \text{dummy terms} - \theta_2 m_t - \theta_3 R_t^X - \sum_{j=1}^{9} \varphi_j \Delta^e \bar{r}_{t+1}^F + \tilde{e}_t^R$$

where m_t is the reserve miss, using the data compiled by the Desk at the New York Fed.[39]

Our results, which appear in the third numeric column of Table 4.1, are similar to those reported in Carpenter and Demiralp (2002). There is strong evidence for the "anticipation effect" in the coefficients on the expected funds rate change. This is also evident in Figure 4.3, which depicts the effective funds rate, the effective funds rate, and the futures-implied target expected to prevail at the next FOMC meeting. More to the point, the liquidity effect now has the correct sign: a higher-than-expected supply of reserves makes the funds rate fall relative to its target, and the effect is highly statistically significant.

One unsatisfactory aspect of the results is that the estimated liquidity effect is minuscule in economic terms. The coefficient of roughly –1 implies that a \$1 billion change in reserves is required to move the funds rate 1 basis point. Taken at face value, the parameter estimate implies that a full percentage point funds rate change would require a \$100 billion change in

[38] These misses occur because Desk's control of reserve supply is imperfect and certain factors, such as changes in the balances held by the Treasury at the Fed, lead to unanticipated fluctuations in the level of reserves. Hamilton's analysis used a model-based reserve forecast error, while Carpenter and Demiralp used the Fed's internal data on the reserve miss.

[39] We are grateful to Spence Hilton and Warren Hrung for providing us with these data.

reserves—more than double the average level of nonborrowed reserves prevailing over the sample. This parameter is misleading, however: because it is distorted by the substitutability of reserves across adjacent days of the maintenance period it cannot be interpreted the slope of a conventional reserve demand function.

The reduced-form Carpenter-Demiralp specification differs from our structural reserve demand equation 4-1 only in its omission of the level of interest rates, and its use of the miss in place of the reserve level. The next set of regressions restoring the interest rate and uses the miss as the instrument for the reserve level to solve the endogeneity problem. We also include a dummy for the lagged reserve accounting (post July 1998) period, which is characterized by greatly reduced volatility in the reserves miss and the funds rate deviation.

Results from this slightly modified equation appear in Table 4.2. The estimated liquidity effect is very similar to that reported in Table 4.1. The instrumented reserve measures have the correct sign, and it makes no difference whether demand is specified in terms of nonborrowed and required reserves, or in terms of excess reserves.

The important result from our standpoint concerns the coefficient on the level of the funds rate, which is basically zero, but with a very large standard error (0.14 or 0.15, depending on which measure of reserves is used). This means we cannot reject the hypothesis that the demand for reserves is perfectly *inelastic* with respect to the level of the fed funds rate. In this case, reserves market could be said to be "decoupled" from the level of interest rates, in the sense that demand depends only on the *spread* between the current effective funds rate and the target. If no reserves were required to change the funds rate, then presumably the announcement effect would be operative.

Reserve supply

We now turn to the flip side of the same question: what does the Desk do when it wants to change the funds rate target? As noted earlier, the answer to this question is obscured by the Desk's efforts to accommodate a variety of factors affecting reserve supply and demand. By controlling for observable factors affecting reserve supply and demand, such as those associated with specific days of the reserve maintenance period and anticipations of future rate changes, regression analysis may be able to discern the actions taken by the Desk to move the funds rate to its new target.

Our starting point is equation 4-2,

$$R^s = \alpha^R - \beta^{RF}\bar{r}_t^F + \lambda\gamma(E_t r_{t+1}^F - \bar{r}_t^F) + u_t^R$$

in which γ parameterizes the sensitivity of reserve demand to deviations from the funds rate target, and λ describes the Desk's tendency to offset those anticipated deviations. Again, we need to modify the equation slightly to accommodate some of the features of the reserves market in the U.S.

First, we note that the reserve supply shock u_t^R includes two distinct components. The first represents the usual noise in the relationship, and factors omitted from the (very simple) model. But a second important component of u_t^R is the reserves "miss" used to identify the reserve demand equation. To recall, the Desk sets some desired level of reserves based its estimate of reserve supply and then, for the reasons discussed above, the realized level of reserves deviates from the desired level. Because we should think of the reserve supply equation as modeling the desired level of reserves, not the actual, it make sense to subtract the miss, m_t, from both sides of the equation, and redefine the dependent variable as the Desk's reserve supply target, $R_t^s - m_t$.

Second, the time subscripts need to be modified slightly to reflect the timing of the reserve supply decision. In brief, the Desk's procedure for setting reserves is to formulate each morning, in collaboration with Board Staff, a forecast for that day's reserve demand and the "autonomous factors" affecting reserve supply. The Desk then enters the market and performs the open market operations necessary to achieve its desired level. The Desk observes the reserve demand and supply shocks, which may have created some unanticipated deviation of the funds rate from its target. Only very rarely does the Desk make additional interventions later in the day in response to realized reserve supply or demand shocks. For this reason, it makes sense to think of the Desk as setting the day's reserve supply in response to that morning's (or in effect the previous day's) information. The appropriate regressor would therefore be $E_{t-1}r_t^F - \bar{r}_t^F$, or that day's expected funds rate deviation. Needless to say, the expected deviation would not include the day t shocks, which are by definition unforecastable. But it could include predictable deviations resulting from the "anticipation effect" discussed above. Our working assumption is that the Desk accommodates these fluctuations to a degree parameterized by the λ coefficient. Variables in the period *t*–1 information set (the previous day's funds rate deviation, the lagged spot month fed funds futures rate, and the futures-based expected change over the maintenance period) will be used as instruments.

Third, for reasons similar to those discussed above in the context of reserve demand, we allow reserve supply to also depend on cumulative excess reserves, R^X_{t-1}, as this is an important predictable factor affecting reserve demand on any given day of the maintenance period.

The equilibrium condition in equation 4-4 implies that the Fed can change reserves to move the effective Fed funds rate, so long as $\beta^{RF} > 0$; and if $\beta^{RF} = 0$, the mere announcement of a new target (and the implied supply schedule) should suffice. An interesting question is whether open market operations are required either to "enforce" or to signal a change in the target. For that reason, we include in the regression the current day's target rate change ($\Delta\bar{r}^F_t$), as well as any change in the funds rate target occurring on previous days of the maintenance period ($\Delta\bar{r}^F_{t-s}$). Enforcement or signaling should presumably only be required when the target change is not already anticipated, so we will use the surprise component of the funds rate change developed in Kuttner (2001) as an instrument for the contemporaneous target rate change.

With these modifications, or empirical specification is

$$R^s_t - m_t = \psi_0 + \psi_1 R^X_{t-1} + \psi_2 \Delta\bar{r}^F_t + \psi_3 \Delta\bar{r}^F_{t-s} + \psi_4 \bar{r}^F_t + \psi_5 (E_{t-1} r^F_t - \bar{r}^F_t) + \tilde{u}^R_t .$$

For comparison, we also estimate a backward-looking version in which $E_{t-1} r^F_t - \bar{r}^F_t$ is replaced with $r^F_{t-1} - \bar{r}^F_t$. The results appear in Table 4.3.

The first numeric column contains the backward-looking version, with nonborrowed reserves as the dependent variable and required reserves included as an additional regressor. As expected, the coefficient on the latter variable is indistinguishable from 1.0. Cumulative excess reserves enters with the expected negative sign.

The estimated ψ_4 of –0.093 is negative, as expected, and statistically significant at the 1% level. This indicates that the Desk supplies lower levels of reserves when the funds rate target rises. And, recalling that ψ_4 can be interpreted as $-\beta^{RF}$, this is consistent with a statistically significant response of reserve demand to the level of interest rates. The effect is very small in economic terms. The funds rate target is expressed in percentage terms, so the point estimate implies that a one percentage point increase in the funds rate is associated with a $93 million reduction (out of roughly $50 billion) in reserve demand.[40]

The statistically significant estimate of the ψ_5 parameter implies that the Desk responds to the previous day's funds rate deviations—positive deviations lead it to inject reserves. Since the deviation is measured in basis points, the point estimate implies that a 10 basis point deviation would lead to a $28 billion change in reserve supply.

The estimates of ψ_2 and ψ_3 provide some evidence for an additional change in reserves on the days of target rate changes. The coefficient on the contemporaneous funds rate change (expressed in basis points) of –0.022 says that a 25 bp target rate change requires a $55 million open market operation. This effect is only marginally significant, however. The coefficient on the lagged change, which is roughly the same magnitude and significant at the 5% level, indicates that the change in reserves is maintained throughout the remainder of the maintenance period. We obtain virtually identical results with excess reserves as the dependent variable instead of nonborrowed reserves.

The results using the forward-looking model, shown in the second numeric column of Table 4, are broadly similar to those of the backward-looking specification. The salient difference is that the coefficient on the expected funds rate deviation is considerably larger, 0.097 versus 0.028, implying a more forceful effort on the part of the Desk to offset expected funds rate deviations. Since the coefficient on reserves in the reserve demand equation represents γ^{-1}, the point estimate implies $\lambda = 0.08$. This is still rather small in the scheme of things, as it implies that approximately 80% of any expected funds rate change is allowed to translate into a change in the effective rate.

Another notable change in the forward-looking model is that the coefficient on the current funds rate is no longer statistically significant, nor does it have the correct sign. Funds

[40] It is interesting to note that the estimated reserve supply equation yielded a better (in the sense of more precise) estimate of $-\beta^{RF}$ than the reserve demand equation. This could be because of the large amount of noise in the funds rate deviation, which would make it hard to discern an effect of the level of interest rates.

rate changes occurring earlier in the maintenance period are still associated with changes in reserves, however, indicating that the Desk tends to follow up on rate changes by adding or draining reserves later in the maintenance period.

Taken together, the estimated reserve supply and demand equations indicate that only very small changes in reserves are required to effect changes in the funds rate—virtually none on the actual day of the target rate change, as indicated by the estimated supply equation. This is consistent with the near verticality of the reserve demand curve. A reasonable inference is that announcement effects play a significant role in moving the funds rate to its new target within the maintenance period. It is therefore not surprising that it should be so hard to discern a link between the quantity of reserves supplied and the equilibrium federal funds rate.

5. Implications and Broader Interpretations

6. New Experience: Monetary Policy During Recent Financial Crises

7. Summary and Conclusions

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Table 3.1: Reserve Demand at the Monthly Frequency

	Dependent variable			
Regressor	Excess reserves + clearing balances	Excess reserves	Nonborrowed reserves	Total reserves
Funds rate (t)	–0.044*	–0.118	–0.011***	–0.002
	(0.023)	(0.088)	(0.004)	(0.007)
Funds rate (t–1)	0.022	0.102	0.009***	0.003
	(0.023)	(0.084)	(0.003)	(0.007)
Required reserves	–0.226	–0.030	0.982***	0.225***
	(0.151)	(0.668)	(0.018)	(0.033)
Demand deposits	–0.270***	0.747***	0.030**	0.018
	(0.102)	(0.291)	(0.014)	(0.018)
Checkable deposits	0.091	0.258	–0.003	0.484***
	(0.164)	(0.771)	(0.031)	(0.045)
Fedwire value	–0.069	0.021	0.010	0.017
	(0.078)	(0.311)	(0.013)	0.020
Fedwire volume	0.251*	0.816*	0.024	–0.044
	(0.141)	(0.503)	(0.021)	(0.031)
Lagged reserves	0.779***	0.342***	0.017	0.351***
	(0.059)	(0.082)	(0.018)	(0.050)
Long-run interest elasticity	–0.095***	–0.0245	–0.0017*	0.0014
FF exclusion *p* value	0.00	0.18	0.00	0.07
R-squared	0.980	0.602	0.998	0.994

Notes: all variables except for the funds rate are in logs. Newey-West corrected standard errors are in parentheses. Asterisks indicate statistical significance: *** for 1%, ** for 5% and * for 10%. The sample is February 1994 through June 2007. The regressions also include an intercept and Y2K dummies. Observations associated with 9/11/2001 are excluded.

Table 4.1: Intra Maintenance Period Estimates of the "Liquidity Effect"

Regressor		Dependent variable = effective fed funds rate – target rate			
Expected funds rate change	Day 1	0.45***	0.48***	0.48***	0.48***
	Day 2	0.25***	0.26***	0.32***	0.32***
	Day 3	0.11**	0.13**	0.14**	0.14**
	Day 4	0.17	0.20	0.20	0.20
	Day 5	–0.08*	–0.05	–0.05	–0.05
	Day 6	–0.06	–0.05	–0.03	–0.03
	Day 7	0.02	0.04	0.05	0.05
	Day 8	–0.07	–0.03	–0.04	–0.04
	Day 9	–0.09	–0.04	–0.06	–0.06
Cumulative excess reserves		–0.68***	–0.64***	–0.72***	–0.57***
		(0.21)	(0.21)	(0.21)	(0.20)
Nonborrowed reserves		0.20***			
		(0.05)			
Excess reserves			0.82***		
			(0.13)		
Reserve "miss"				–0.95***	–0.73***
				(0.32)	(0.22)
Adjusted R^2		0.11	0.11	0.11	0.11
Method		OLS	OLS	OLS	WLS

Notes: daily data, January 1 1994 through December 31 2006, 3338 observations. Y2K and 9/11 observations are excluded. Robust Newey-West standard errors are in parentheses. WLS regression uses estimated residual variance pre- and post- July 20 1998 (the shift to lagged reserve accounting). Asterisks denote level of statistical significance: *** for 1%, ** for 5% and * for 10%. The regressions also include dummies for day of the maintenance period, the last day of the month, days with no FOMC meeting within the maintenance period, and settlement Wednesdays.

Table 4.2: Intra Maintenance Period Estimates of Reserve Demand

	Regressor	Dependent variable = effective fed funds rate – target rate	
Expected funds rate change	Day 1	0.45^{***}	0.44^{***}
	Day 2	0.37^{***}	0.36^{***}
	Day 3	0.18^{***}	0.17^{***}
	Day 4	0.14^{***}	0.14^{***}
	Day 5	0.02	0.01
	Day 6	0.02	0.01
	Day 7	0.11^{*}	0.10
	Day 8	0.01	0.00
	Day 9	–0.04	–0.06
	Cumulative excess reserves	-0.67^{***}	-0.66^{***}
		(0.19)	(0.19)
	Nonborrowed reserves†	–0.86	
		(0.28)	
	Required reserves	0.74^{***}	
		(0.28)	
	Excess reserves†		–0.87
			(0.29)
	Lagged reserve accounting dummy	-3.34^{**}	-2.02^{**}
		(1.31)	(0.86)
	Target fed funds rate	–0.03	0.04
		(0.15)	(0.14)

Notes: daily data, January 1 1994 through December 31 2006, 3338 observations. Y2K and 9/11 observations are excluded. Estimation method is weighted 2SLS, using the reserves "miss" (plus the other exogenous variables) instruments, using as weights the estimated residual variance pre- and post- July 20 1998; the † marks the variables treated as endogenous. Robust Newey-West standard errors are in parentheses. Asterisks denote level of statistical significance: *** for 1%, ** for 5% and * for 10%. The regressions also include dummies for day of the maintenance period, the last day of the month, days with no FOMC meeting within the maintenance period, and settlement Wednesdays.

Table 4.3: Intra Maintenance Period Estimates of Reserve Supply

Regressor	Dependent variable: Nonborrowed reserves		Dependent variable: Excess reserves	
Required reserves	–0.978***	0.979***		
	(0.01)	(0.013)		
Cumulative excess reserves	–0.121*	–0.057	–0.124*	–0.058
	(0.050)	(0.053)	(0.051)	(0.053)
Change in target rate†	–0.022*	0.028	–0.024*	0.025
	(0.011)	(0.019)	(0.012)	(0.018)
Prior target rate change	–0.019**	–0.020**	–0.020**	–0.021**
	(0.009)	(0.009)	(0.009)	(0.009)
Target federal funds rate	–0.093***	–0.105***	–0.050	–0.062**
	(0.032)	(0.034)	(0.031)	(0.031)
Lagged funds rate deviation	0.028***		0.029***	
	(0.005)		(0.005)	
Expected funds rate deviation†		0.097***		0.097***
		(0.014)		(0.014)
Adjusted R^2	0.87		0.33	
J stat *p*-value		0.934		0.921
Method	OLS	2SLS	OLS	2SLS

Notes: daily data, January 1 1994 through December 31 2006, 3334 observations. Y2K and 9/11 observations are excluded. Robust Newey-West standard errors are in parentheses. Asterisks denote level of statistical significance: *** for 1%, ** for 5% and * for 10%. The regressions also include dummies for day of the maintenance period, the last day of the month, days with no FOMC meeting within the maintenance period, and settlement Wednesdays. The instruments used for the 2SLS regressions are the lagged funds rate deviation, the lagged spot-month fed funds futures rate, the lagged futures-implied funds rate change within the maintenance period, and the futures-based funds rate surprise (plus the other exogenous variables); the † marks the variables treated as endogenous.

Figure 3.1

Supply-Induced Changes in the Policy Interest Rate

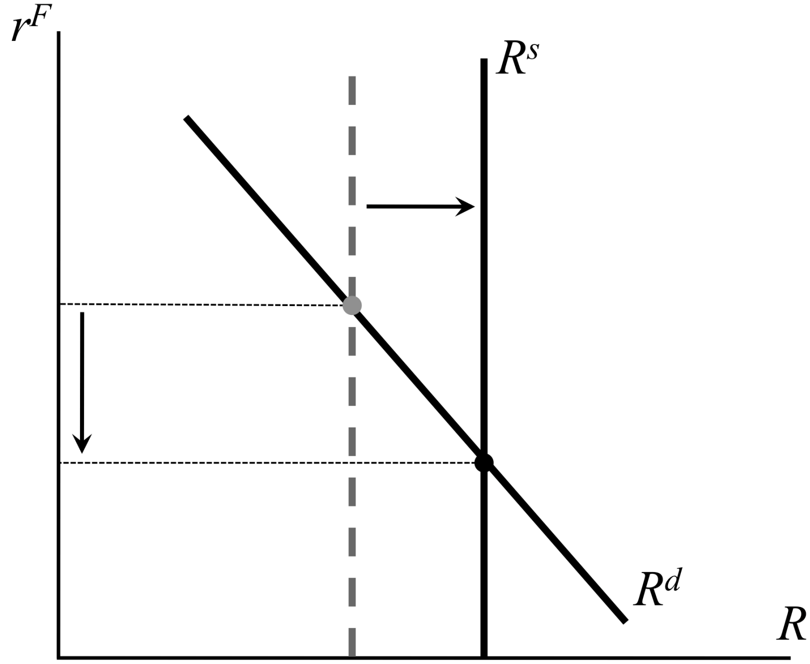
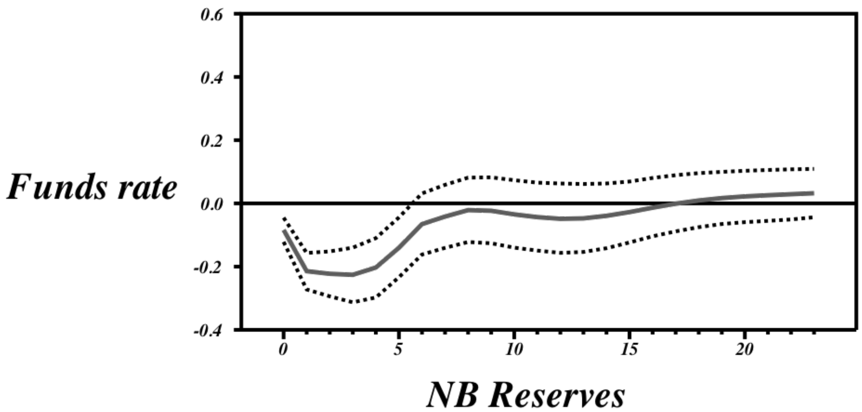


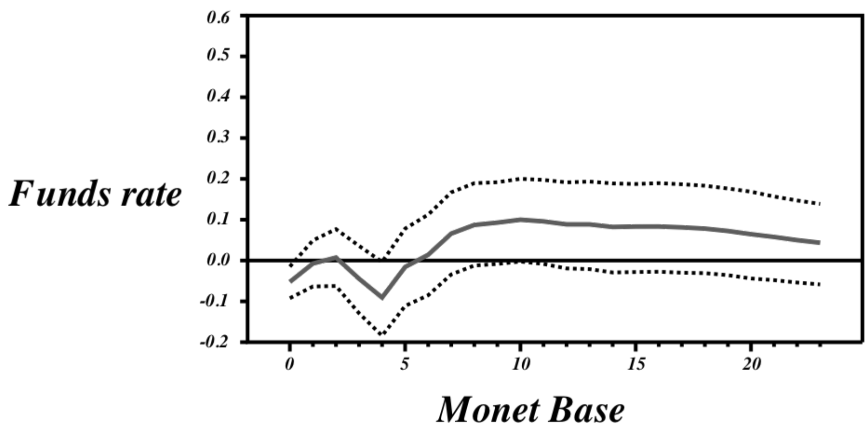
Figure 3.2

VAR Estimates of the Liquidity Effect at the Monthly Frequency

Panel A: Nonborrowed reserves, 1982–1993



Panel B: Monetary Base, 1982–1993



Panel C: Nonborrowed reserves, 1994–2007

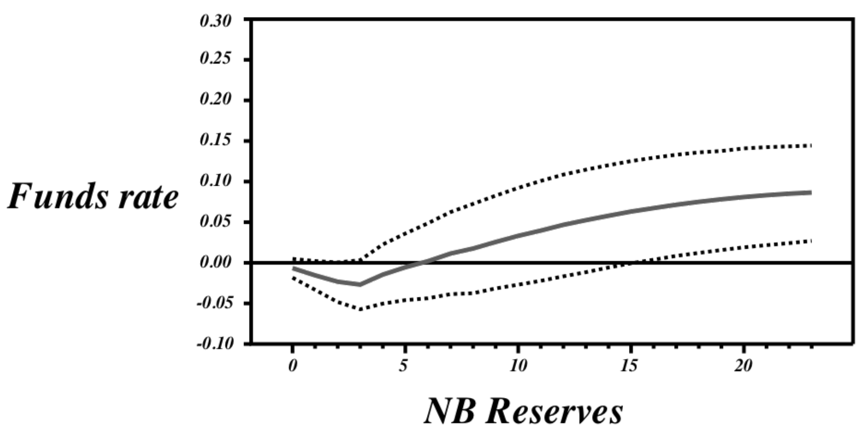


Figure 3.3

Nonborrowed, total reserves; reserves + clearing balances

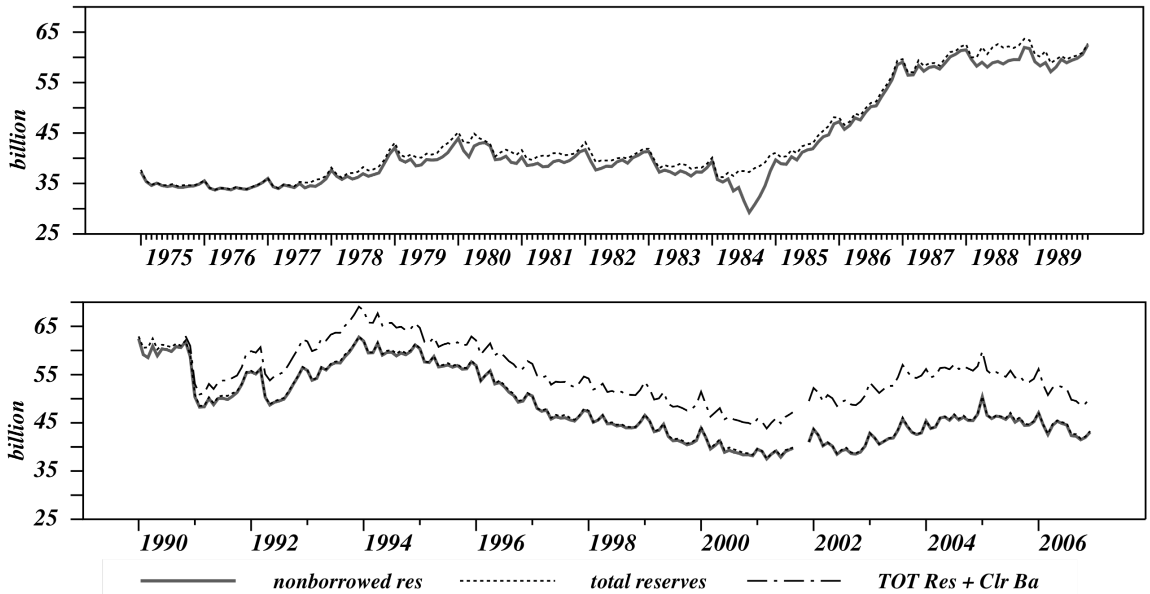
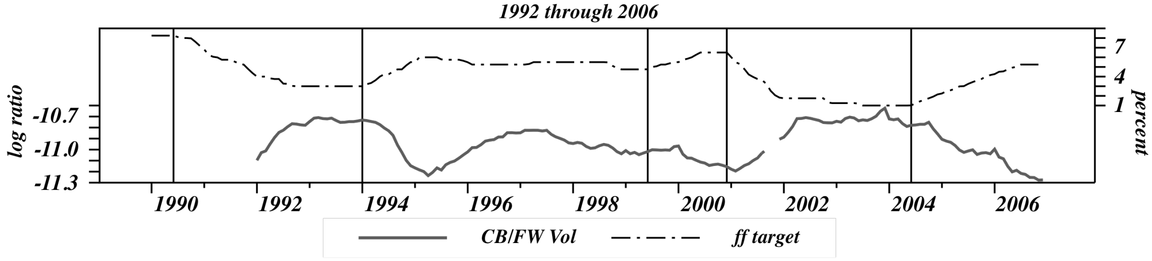


Figure 3.4

Log ratio of clearing balances to Fedwire volume and the funds rate

1992 through 2006



Log excess reserves and the funds rate

1990 through 2006

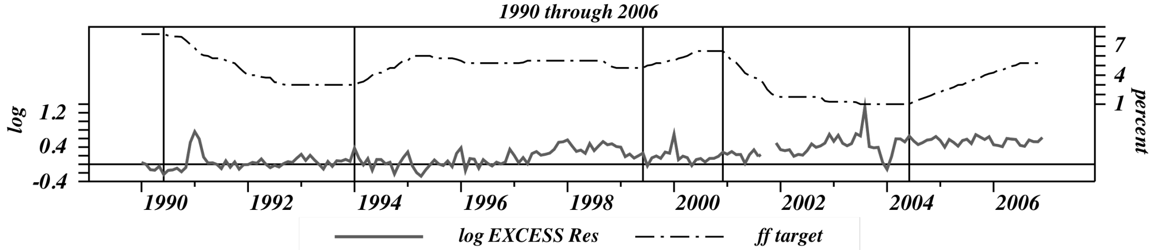
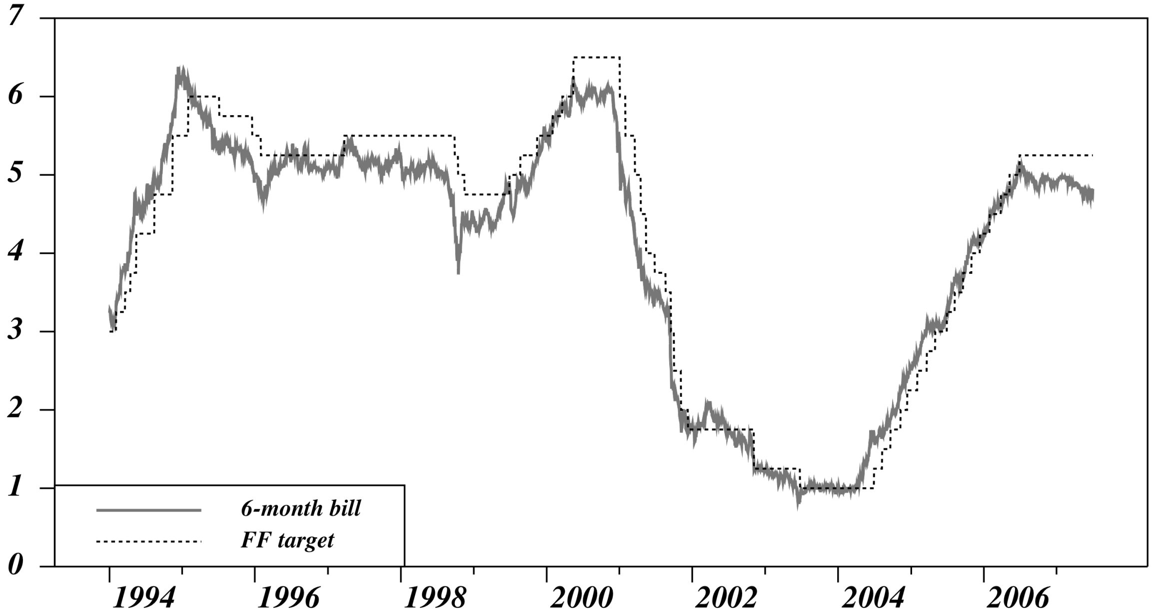


Figure 3.5

The Relationship Between the Funds Rate Target and Treasury Bill Rates

Panel A: The Target Funds Rate and the 6-Month Bill Rate



Panel B: Funds Rate Surprises and Changes in the 6-Month Bill Rate

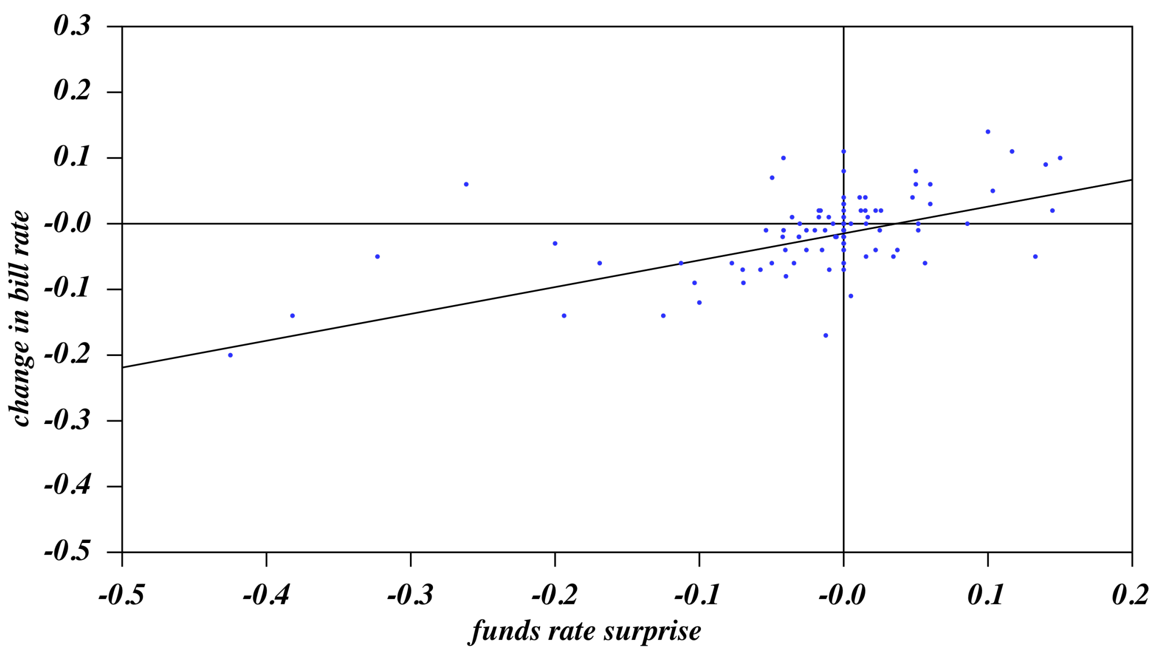


Figure 4.1

Supply-Induced Interest Rate Changes With No Change in Reserves

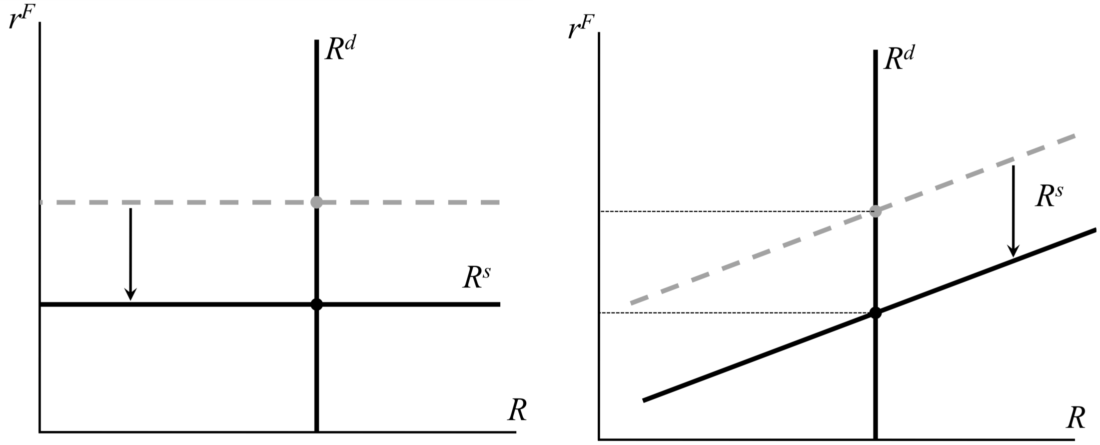


Figure 4.2

Demand-Induced Interest Rate Changes With No Change in Reserves

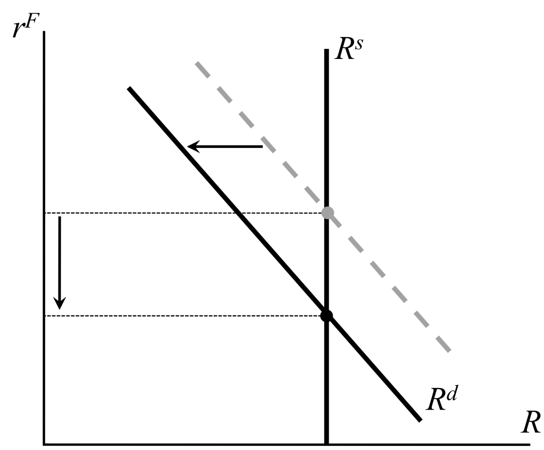


Figure 4.3

The Anticipation Effect