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Abstract

Most current literature assumes that a central bank loses the ability to influence interest rates through variations in reserve supply as soon as overnight rates have been driven to zero. In this paper I argue that reserve supply can be directly related to longer-term rates when overnight rates are zero, because banks' reserve demand is then defined by the role of cash as an asset free of interest-rate risk. I present evidence that reserve supply affected longer-term interest rates in the U.S. from 1934 through 1939, during which overnight rates were at the zero floor, even when the changes in reserve supply reflected factors unlikely to have affected expectations of future overnight rates.

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1. Introduction[1]

In the 1990s, an experience of relatively low inflation and nominal interest rates in the U.S. and Europe, and the advent of a major depression in Japan accompanied by short-term interest rates barely above zero, revived interest in the “liquidity trap” as a potential constraint on monetary policy (for example Summers, 1991; Fischer, 1996). Krugman (1998) argues that 1990s Japan was indeed in a liquidity trap, defining that to be “a situation in which conventional monetary policies have become impotent, because nominal interest rates are at or near zero: injecting monetary base into the economy has no effect” (p. 141).

Most recent discussions of the liquidity trap argue (or assume) that it constrains a central bank’s ability to control interest rates at *any* maturity as soon as interest rates have been pushed to zero at the *shortest* maturity — in modern financial markets, overnight rates. Monetary policy may still be able to influence real activity through exchange rates (Orphanides and Wieland, 2000; Svensson, 2000; McCallum, 2001) or effects of real money balances on demand for assets in general, including durable goods (Brunner and Meltzer, 1968a; Meltzer, 2001). But the “interest rate channel” of monetary policy — special influence over yields on liquid assets, and hence on required returns for less liquid financial assets such as bank loans — is blocked. In the common view, a central bank influences longer-term rates through expectations of future overnight rates, while overnight rates are sensitive to liquidity effects of reserve supply. Term premiums are generally believed to be unaffected by central bank operations except to the degree that the yield curve can be twisted by changes in the maturity structure of government debt, which is doubtful (Johnson, Small and Tryon, 1999; King, 1999; Eggertsson and Woodford, 2003, pp. 20-23). Thus, it is asserted, once overnight rates have been driven to their floor, a central bank has no way to

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influence longer-term rates because it has no mechanism to validate, or contradict, the expectations that determine them. Perhaps the central bank can make announcements or adopt rules to boost the public's confidence that overnight rates will remain zero further into the future, but if expectations do not respond as desired the central bank cannot enforce a decrease in longer-term rates by increasing reserve supply (Fuhrer and Madigan, 1997; Krugman, 1998 and 2000; McCallum, 2000; Meyer, 2001; Woodford, 1999).

From 1934 through 1939 the United States was in a situation that amply satisfied this current definition of a liquidity trap. Though long-term rates remained well above zero — long-term Treasury yields never fell below two percent — the overnight rate had clearly been driven to the floor, while Treasury bill rates were often less than half a percent and sometimes effectively zero. According to Krugman (1998), U.S. interest rates were "hard up against the zero constraint" (p. 137) in this period. Meanwhile, the monetary policies followed by the Federal Reserve Board and the U.S. Treasury caused fluctuations in reserve quantities that were clearly shocks to the supply of high-powered money, rather than responses to money demand. Some supply shocks were associated with news about monetary policy, but others were the result of transient factors arguably unrelated to news about monetary policy.

In this paper I examine evidence from the 1930s U.S. on the relation between reserve supply and longer-term interest rates in an environment of zero overnight rates. To begin, I argue that most recent discussions of liquidity traps overlook an important idea from the money-demand literature of the 1930s-50s: the potential role of money as an asset free of interest-rate risk, which implies that money demand is a function of longer-term interest rates when the overnight rate is zero. I present a model to illustrate how this could apply to banks' demand for reserves, and how it interacts with the role of reserves as a transactions medium. The model reproduces conventional propositions about interest rates and reserve supply when overnight rates are positive, but when the overnight rate is zero an increase in reserve supply can cause long-term rates to fall even if there is no change in expectations of future overnight rates. Finally I examine the relation between reserve quantities and bond yields over 1934-39. I find that changes in bond yields were negatively related to reserve supply shocks in a manner consistent with the model.

2. Reserve demand and the liquidity trap: issues

A common model of reserve demand and interest-rate determination in the United States frames much academic literature and discussion by policymakers. Poole (1968) is an early formal presentation. Recent work based on the model or similar models includes Strongin (1995), Hamilton (1996 and 1997), Borio (1997), Bernanke and Mihov (1998), Woodford (2000), Bartolini, Bertola and Prati (2002). The model rests on an institutional framework that has been in place since the early 1920s. Banks that hold reserve accounts in the Federal Reserve system can borrow and lend overnight through a variety of instruments. In the 1920s the most important was the “call money” or “brokers’” loan collateralized by baskets of assets traded on the New York stock exchange. Call money was generally considered to be risk-free to the lender, because a substantial margin between the current collateral value and the loan amount guarded against drops in securities’ prices (Haney, Logan and Gavens, 1932). Other overnight instruments included interest-paying demand deposits; repurchase agreements (repos) on federal securities (United States Senate, 1931, Part 1, p. 1048); and federal funds loans, that is (usually) uncollateralized loans between institutions holding accounts in the Federal Reserve system (Turner, 1931). Today the set of overnight instruments is much the same, though repos are more important, brokers’ loans are less important and interest-paying interbank deposits are booked offshore as “eurodollars” to evade regulations.

At the end of each business day, after it is *no longer possible* for a bank to borrow or lend overnight or buy and sell securities, the Federal Reserve system ceases to clear payments, and calculates a final balance in banks’ reserve accounts. Before this time a bank cannot know exactly what its end-of-day balance will be, because many types of payments are cleared with an unpredictable lag (Federal Reserve Board, 1930 and 1996, p. 4; Turner, 1931, p. 51). The final balance must not fall below zero on any day, or below a required minimum balance on average over a “maintenance period” that is nowadays two weeks long, in the 1930s just three days for large banks (Morrison, 1966, p. 122). If a bank’s balance is deficient, the bank must pay a penalty or borrow enough from the “discount window” to cover the deficiency. Through most of the 1920s and 1930s, and again today (since the adoption of “primary credit” lending in January 2003 [Federal Reserve Board, 2002]), the rate charged for discount loans is a “penalty” rate set higher than market short-term rates. At other times the discount rate has been set below market overnight rates but the effective cost of discount borrowing was higher because discount credit was rationed by the Fed, and perhaps because banks feared that discount borrowing could be taken as a signal of financial distress (Clouse, 1994; Whitaker, 1930, pp. 93-94; Riefler, 1930, p. 29). The required minimum balance was, in the 1920s and 1930s, simply the bank's "required reserve." Today it is the "required operating balance": the required reserve *plus* the bank's required clearing balance *less* vault cash (Feinman, 1993). In the long run, a bank's required minumum balance is affected by changes in market interest rates, partly because nonbanks' demand for reservable bank deposits is sensitive to interest rates in a conventional "money demand" function. But there are lags in the response of monetary aggregates to interest rates (Small and Porter, 1989) (and also in the application of banks' adjustments to their required clearing balances [Edwards, 1997]), so a bank's required minimum reserve balance is effectively pre-determined within a short run of some weeks.

In a model with assumptions reflecting these facts, a bank weighs the return to overnight lending, or the cost of overnight borrowing, against the value of leaving another dollar in its reserve account to reduce the probability of a reserve deficiency, and the resulting cost of discount borrowing to cover a deficiency. This creates a negative relation between the overnight rate and the quantity of reserves a bank chooses to hold in its reserve account *in excess* of the required minimum, *before* any borrowing from the discount window. In Federal Reserve data, this quantity corresponds to "free reserves": nonborrowed reserves (total reserves less short-term discount borrowing), *less* required reserves (in the 1920s and 1930s) or required operating balances (today). Other things equal, an increase in free reserve supply tends to reduce the overnight rate. This "liquidity effect" is evident in data from recent years (Hamilton, 1997) and was also apparent in the 1920s (Riefler, 1930, p. 27; Brunner and Meltzer, 1968b; Wheelock, 1991).

By itself, the common model of reserve demand is consistent with the proposition that changes in reserve supply have no effect on longer-term interest rates once the overnight rate has been driven to zero: in that circumstance, the model leaves reserve demand *indeterminate*, satisfying the basic condition for a liquidity trap (King, 1999, p. 39). I argue, however, that the model omits a factor that can define banks' reserve demand as a function of longer-term rates when overnight rates are zero: the potential role of cash as an asset free of interest-rate risk.

In the money-demand literature of the 1930s through the 1950s, it was often asserted that nonbanks hold cash and demand deposits not only to carry out transactions, but also to avoid interest-rate risk on other assets. Keynes (1936) refers specifically to the risk that interest rates might rise above a current abnormally low level, and describes the lost interest earnings on a money balance as “a sort of insurance premium to offset the risk of loss on capital account” (p. 202). Tobin (1958) clarifies the distinction between such one-sided risk and more general uncertainty about future interest rates and bond prices, showing that two-sided risk together with the “theory of risk-avoiding behavior” implies “an inverse relationship between the demand for cash and the rate of interest” (p. 85).

Since the 1950s, the money-demand literature has turned away from interest-rate risk because it is assumed that there are “substitutes for money, typically short-term money market instruments, which can be regarded as riskless ... and which pay substantial interest” (Chang, Hamberg and Hirata, 1983). McCallum and Goodfriend (1987) point out that “rate-of-return uncertainty on other assets cannot be used to explain why individuals hold money in economies — such as that of the US — in which there exist very short-term assets that yield positive interest” (p. 779; see also Barro and Fischer, 1976). But what if very short-term rates were zero? Then the mechanism described by Keynes and Tobin would come into play, even if it does not operate when the overnight rate is positive (Hicks, 1967, p. 27). Indeed, conventional money-demand functions, specifying negative relations between bill rates and aggregates of cash and deposits held by nonbanks, appear to hold in the 1930s as well as in postwar periods (Meltzer, 1963, p. 242; Gandolfi and Lothian, 1976, p. 50).

Viewing money demand as determined by interest rates in general, rather than short-term rates in particular, Keynes described the liquidity trap in terms of long-term rates, and did not think it was binding in the mid-1930s. He admitted that open-market operations in bills were useless if bill rates had been driven to zero, for in that case bills were equivalent to money, but there was still a well-determined demand for money broadly defined as cash *plus* bills (Hicks, 1982, p. 263). Thus, he argued, a central bank could drive down long-term rates by purchasing longer-term bonds (Keynes, 1930, p. 371; 1936, p. 207).

A missing link in Keynes' argument is a consideration of banks' demand for reserves, as distinct from nonbanks' demand for deposits and cash. This distinction was ignored by nearly all of the money demand literature of the 1930s-50s.[2] But it is obviously important here. Monetary authorities' purchases of bonds or other assets such as foreign exchange will still be useless if banks are willing to hold the resulting increase in high-powered money as reserves without any change in longer-term interest rates. That will be the case if reserve demand is indeterminate under zero overnight rates, as today's common model of reserve demand appears to suggest.

Suppose, however, that banks also hold cash to avoid interest-rate risk when overnight rates are zero. A bank's managers have obvious reasons to avoid loss of capital, whether or not they display other forms of risk aversion. Bank regulators have tried to guard banks' creditors and deposit insurance agencies against bank insolvency by requiring a bank to maintain a standard margin of capital between the value of its assets and liabilities (Jones, 1940; Madden, Nadler and Heller, 1948, pp. 111-26; Kaufman, 1992; Caprio and Honahan, 1999). Apart from regulatory constraints, a bank might need to hold a capital margin in order to maintain the confidence of creditors holding short-term bank debt. According to Benston and Kaufman (1994): "Before federal deposit insurance, capital was seen as the primary protection for depositors ... Indeed, banks prominently displayed signs in their front windows stating 'Capital and Surplus $XX million.'" (p. 2). Certainly, bankers have always paid attention to potential assets' relative degrees of interest-rate risk, with an eye to the bank's ability to pay off depositors as well as satisfy regulators (Ames, Emerich and Company, 1928; McKee, 1929; Ebersole, 1931, pp. 354-72; Ayers, 1937; Robinson, 1940, pp. 181-82; Bradford, 1941, pp. 446-47; Houpt and Embersit, 1991, pp. 625-27). In the 1930s, a banker observed: "We are vitally interested in protecting our capital funds from depreciation when the ultimate increase in interest rates comes and brings along a depreciation in longer term securities" (quoted in Meltzer, 2003, p. 507). At the same time,

[2] Exceptions include a 1940 memo by Federal Reserve staff economist Emile Despres (described by Meltzer, 2003, pp. 553-54) and Samuelson (1942), who briefly observes that "It is more and more being realized that reserves do not perform the function of till money. Rather they are felt to be necessary for the maximization of income over time in a world where uncertainty dictates a diversification of portfolios" (footnote 3, p. 594).

bankers complained that the low level of interest rates weakened banks' capital positions, because they reduced earnings (p. 548).

If overnight rates have been driven to zero, a bank could be indifferent between cash and any other assets paying zero yields. That might include short-term bills, if it has become certain that overnight rates will remain zero for some months. But a bank that needs to preserve capital could not be indifferent between cash and longer-term bonds paying positive yields. At that margin there is a tradeoff of expected return against interest-rate risk, similar to the margin between bonds and overnight loans when overnight rates are positive.

What does this imply for the relation between reserve quantities and longer-term interest rates when the overnight rate is zero? How does this potential role for reserves interact with the factors described by standard models of reserve demand and overnight rates? In the next section of the paper, I present a model to partially answer these questions.

3. The model

3.1 Overview of the model

This model describes the reserve-demand behavior of profit-maximizing banks and resulting relations between interest rates and reserve quantities, assuming that a bank faces a cost if it fails to maintain a required minimum reserve and another cost if it falls short of a capital standard, while the bank is uncertain about future prices of long-term assets and the timing of payments to its reserve account. The model is meant to describe relations between variables on a short frequency — day-to-day or week-to-week — so it takes as given the quantity of deposits and cash held outside banks, on the argument that nonbank demand for these assets responds to interest rates only with a substantial lag. The model is also meant to focus on the interest-rate channel and the potential relation between reserve supply and long-term rates. The potential equivalence of cash and zero-yield bills is not at issue. Thus, for simplicity, the only asset in the model other than deposits, cash and overnight loans is a liquid long-term bond. The spread between the overnight rate and the expected overnight yield to bonds is the term premium in the model. Also for simplicity, it is assumed that costs of a reserve deficiency or a capital shortfall increase linearly with the size of the deficiency or shortfall; the reserve requirement must be met at the end of every day (which was close to the truth in the 1930s); and the required margin of capital is zero (a bank satisfies the capital standard as long as its liabilities do not exceed the value of its assets). Reflecting the institutions of the 1930s, I assume that a bank cannot pay interest on demand deposits (Regulation Q). I also assume that a bank's vault cash counts toward meeting its reserve requirement. That matches today's rules rather than those of the 1930's, but it will become clear that this assumption does not matter in the case where the overnight rate is zero.

In the model, the overnight rate is positive or zero depending on the supply of free reserves, that is reserves less required minimum balances. The overnight rate is positive if free reserve supply per bank is small enough, relative to the magnitude of unpredictable payment flows, that a bank sometimes finds itself with a reserve deficiency. For this case I show that, under reasonable conditions, the model is equivalent to standard models of reserve demand: a boost to free reserve supply reduces the market overnight rate, but it does *not* tend to reduce the term premium. The last point is important, as the conventional view does not allow for a negative relation between reserve supply and term premiums under "normal" circumstances.

The overnight rate falls to zero if free reserve supply per bank is great enough to eliminate the danger of a reserve deficiency. In this case the quantity of reserves demanded by a bank is defined by the tradeoff of the expected overnight bond yield against the value of cash in reducing the probability of a capital shortfall. For this case I show that reserve supply is positively related to the bond price *holding fixed* expectations of future overnight rates. Thus, a monetary policy action that increases the supply of reserves can raise the bond price and depress its yield to maturity, even if the action has no effect on expected future overnight rates. This is because a bank is unwilling to hold a greater quantity of reserves without a decrease in the expected overnight bond yield, other things equal. The reserve quantity that matters here, however, is not free reserves but rather reserves *including* required reserves. That is to say, given the quantity of reserves, the market-clearing bond price is unaffected by changes in required minimum reserves. That is because a change in a bank's required reserve has no effect on the value of cash as an asset to avoid interest-rate risk.

3.2 Assumptions and notation

Today's overnight rate, expressed as a fraction on a daily basis, is denoted *i*. A bond is a promise of payment(s) on certain date(s) later than tomorrow. Today's bond price is P. Tomorrow's bond price P_{+1} is uncertain. Expectations of future term premiums and overnight rates determine a common set of beliefs about P_{+1}, described by an expected value P_{+1}^{e} and a distribution for the possible mean-zero error ε in the expectation ($\varepsilon = P_{+1} - P_{+1}^{e}$) with a c.d.f. F_P and a p.d.f. f_P. Revisions to expectations of future overnight rates or future term premiums correspond to changes in the value of P_{+1}^{e} and/or the distribution of ε. The minimum value of ε is $(-P_{+1}^{e})$, since the bond price cannot fall below zero. The expected overnight yield to holding bonds is $\frac{P_{+1}^{e}}{P} - 1$. The degree of uncertainty in the yield is described by the magnitude of the distribution for ε relative to *P*. The spread between the expected overnight bond yield and the overnight rate, corresponding to a term premium, is:

$$s = \frac{P_{+1}^{e}}{P} - (1+i) \tag{1}$$

There are many identical banks. A bank takes deposits and holds bonds, vault cash and a balance on the books of the Central Bank. I refer to the sum of a bank's vault cash and its central bank balance as the bank's "reserve." If the overnight rate is positive, a bank can also lend overnight, or borrow. If the market-clearing overnight rate is zero there is no overnight lending, because for a potential lender a bank deposit dominates an overnight loan at zero interest. Today, a bank takes as given its deposits *D*, its bondholdings carried over from the previous day denoted B_{-1}, and its initial cashholding C. If yesterday's overnight rate was zero, C is the reserve carried into the day. If yesterday's overnight rate was positive, C is the bank's reserve *plus* the principal and interest on yesterday's overnight lending by the bank. (C can take a negative value if the bank borrowed enough yesterday.) The total value of the bank's assets given today's bond price is $A = PB_{-1} + C$. The bank's capital balance today is $A - D$. During the day, the bank can reallocate its assets by buying or selling bonds and — if the overnight rate is positive — borrowing or lending overnight. This leaves the bank with a bondholding B to carry into tomorrow, and a reserve quantity denoted R. If today's overnight rate is positive, the bank's overnight lending is equal to $A - PB - R$ (which is negative if the bank is borrowing overnight). If today's overnight rate is zero, the bank's reserve and the value of its bondholding sum to the bank's asset value: $A = P\,B + R$.

At the end of the day, after it is no longer possible to engage in overnight lending or bond sales, the Central Bank will take a balance in the bank's account. Because of unpredictable lags in processing payments, the resulting reserve quantity will be $R + \delta$, where δ is a random variable that is independent of ε (the error in the expectation of tomorrow's bond price) and sums to zero across all banks (one bank's delayed debit is another bank's credit). During the day, the bank's beliefs about possible values of δ are described by a distribution with a c.d.f. F_D and p.d.f. f_D, and upper and lower bounds of $\overline{\delta}$ and $\underline{\delta}$. The bank suffers a *reserve deficiency* if its reserve after clearing $R + \delta$ falls below a required level RR, which is to say if $\delta < -(R - RR)$. The bank's *free reserve* is $R - RR$. The probability of a reserve deficiency is $F_D\{-(R - RR)\}$, where $F_D\{-(R - RR)\} = 0$ for $R - RR \geq -\underline{\delta}$: a large enough free reserve eliminates the danger of a reserve deficiency. In the event of a reserve deficiency the bank is subject to a penalty of ρ per dollar of deficiency, with a total cost equal to $\rho(-(R - RR) - \delta)$.

In addition to the reserve requirement, a bank is subject to a special cost if its capital falls below zero. The cost is equivalent to λ per dollar of capital shortfall. I assume that a bank has sufficient capital today: $A - D \geq 0$. But tomorrow's capital balance is uncertain. Tomorrow's asset value A_{+1} will depend on tomorrow's bond price P_{+1}, and on whether the bank meets the reserve requirement tonight. Assuming that the bank meets the reserve requirement tonight, tomorrow's capital balance will be:

$$A_{+1} - D = P_{+1}\, B + (1+i)\,(A - PB - R) + R - D \;= (1+i)\, A - D - i\, R + s\, P\, B + B\, \varepsilon \tag{2}$$

The bank will fall short of capital if $A_{+1} - D < 0$. This occurs in the event that:

$$\varepsilon < X_1 \quad \text{where} \quad X_1 = - sP - \tfrac{(1+i)A - D - iR}{B} \tag{3}$$

Assuming that the bank *fails* to meet tonight's reserve requirement, tomorrow's assets will be reduced by the reserve deficiency cost $\rho\,(-(R - RR) - \delta)$ and the bank will fall short of capital if:

$$\varepsilon < X_2 \qquad \text{where} \quad X_2 = - sP - \tfrac{(1+i)A - D - iR - \rho(-(R - RR) - \delta)}{B} \tag{4}$$

Overall, the probability that the bank will fall short of capital is:

$$\begin{aligned} &\int_{-(R-RR)}^{\bar{\delta}} \int_{-P^e_{+1}}^{X_1} f_P\{\varepsilon\} d\varepsilon\, f_D\{\delta\}\, d\delta + \int_{\underline{\delta}}^{-(R-RR)} \int_{-P^e_{+1}}^{X_2} f_P\,\{\varepsilon\} d\varepsilon\, f_D\{\delta\}\, d\delta \\ &= F_P\{X_1\} + \int_{\underline{\delta}}^{-(R-RR)} \int_{X_1}^{X_2} f_P\{\varepsilon\} d\varepsilon\, f_D\{\delta\} d\delta \end{aligned} \tag{5}$$

The first term on the second line of expression (5), $F_P\,\{X_1\}$, would be the probability of a capital shortfall if there were no potential cost of an overnight reserve deficiency. The remaining term is the *extra* probability of a capital shortfall caused by the potential cost of a reserve deficiency. The practical importance of the extra term depends on the magnitude of possible reserve deficiency costs $\rho\,(-(R-RR)-\delta)$ relative to today's bank capital and the range of uncertainty about tomorrow's bond values, as determined by the relative size of ρ (the penalty per dollar of reserve deficiency) and possible values of δ (unpredictable payment lags). Realistically, possible values of $\rho\,(-(R-RR)-\delta)$ may be *small* relative to bank capital and bond value uncertainty. If so, the extra probability is close to zero (because $f_P\{X_1\}$ is approximately equal to $f_P\{X_2\}$ for any possible value of δ) whatever the value of $F_P\{X_1\}$. That is to say, the possible cost of an overnight reserve deficiency has little effect on the probability that the bank will suffer a capital shortfall tomorrow.

A bank takes as given today's bond price *P* and conditions in the overnight lending market, and acts to maximize expected profit. That is the same as maximizing the expected value of the bank tomorrow, denoted *V*. The bondholding and reserve quantity that maximize *V* are denoted *B** and *R**.

3.3 When the overnight rate is positive

If today's overnight rate is positive:

$$V = (1+i)\,A - D - i\,R + s\,P\,B - \rho \int_{\underline{\delta}}^{-(R-RR)} (-(R-RR)-\delta)\, f_D\{\delta\} d\delta \tag{6}$$

$$-\lambda \int_{-(R-RR)}^{\bar{\delta}} \int_{-P^e_{+1}}^{X_1} -\big(\,(1+i)A - D - iR + sPB + B\,\varepsilon\,\big)\, f_P\{\varepsilon\}\, d\varepsilon\, f_D\{\delta\}\, d\delta$$

$$-\lambda \int_{\underline{\delta}}^{-(R-RR)} \int_{-P^e_{+1}}^{X_2} -\big(\,(1+i)A - D - iR + sPB + B\,\varepsilon - \rho(-(R-RR)-\delta)\,\big)\, f_P\{\varepsilon\}\, d\varepsilon\, f_D\{\delta\}\, d\delta$$

Assuming that the distributions for δ and ε are smooth and unimodal, R^* and B^* satisfy first-order conditions:

$$\tfrac{\partial V}{\partial R} = 0 = -i + \rho F_D\{-(R^* - RR)\} + \lambda F_P\{X_1\}(-i + \rho F_D\{-(R^* - RR)\}) \tag{7}$$

$$+ \lambda \int_{\underline{\delta}}^{-(R^*-RR)} \int_{X_1}^{X_2} (\rho - i) f_P\{\varepsilon\} d\varepsilon \, f_D\{\delta\} d\delta$$

$$\tfrac{\partial V}{\partial B} = 0 = s P - \lambda F_P\{X_1\}\left(-sP - E\left[\varepsilon \mid \varepsilon < X_1\right]\right) - \lambda \int_{\underline{\delta}}^{-(R^*-RR)} \int_{X_1}^{X_2} -(sP + \varepsilon) f_P\{\varepsilon\} d\varepsilon \, f_D\{\delta\} d\delta \tag{8}$$

where $X_1 = -sP - \frac{(1+i)A - D - iR^*}{B^*}$ $\qquad X_2 = -sP - \frac{(1+i)A - D - iR^* - \rho(-(R^* - RR) - \delta)}{B^*}$

The value of the overnight rate i that clears financial markets, denoted $\hat{i}$, is such that reserve demand R^* equals the *supply* of reserves per bank R^S. Substituting R^S into expression (7) and rearranging gives:

$$\hat{i} = \rho F_D\{-(R^S - RR)\} + \tfrac{\lambda(\rho - \hat{i})}{1 + \lambda F_P\{X_1\}} \int_{\underline{\delta}}^{-(R^S-RR)} \int_{X_1}^{X_2} f_P\{\varepsilon\} d\varepsilon \, f_D\{\delta\} d\delta \tag{9}$$

where $X_1 = -sP - \frac{(1+\hat{i})A - D - \hat{i}R^S}{B^*}$ $\qquad X_2 = -sP - \frac{(1+\hat{i})A - D - \hat{i}R^S - \rho(-(R^S - RR) - \delta)}{B^*}$

Expression (9) defines the conditions under which the market overnight rate is positive, or zero. $\hat{i}$ must be zero if $R^S - RR$ is greater than $(-\underline{\delta})$, that is if free reserve supply is great enough to eliminate the danger of an overnight reserve deficiency. Otherwise $\hat{i}$ is positive.

Assuming $\hat{i}$ is positive, the practical implications of (9) depend on the relative magnitude of possible reserve deficiency costs $\rho(-(R-RR)-\delta)$. If they are small relative to bank capital and uncertainty about tomorrow's bond values, the second term on the right-hand side of (9) can be negligible so that:

$$\hat{i} \approx \rho\, F_D\{-(R^S - RR)\} \tag{10}$$

and:

$$\tfrac{\partial \hat{i}}{\partial R^S} \approx -\rho\, f_D\{-(R^S - RR)\} \tag{11}$$

Expressions (10) and (11) match conventional models of reserve demand and overnight-rate determination: the prevailing overnight rate is effectively determined by *free* reserve supply $R^S - RR$ and the cost of a reserve deficiency, given banks' beliefs about possible payment flows in end-of-day settlement. The overnight rate falls in response to an increase in free reserve supply — either an increase in the quantity of nonborrowed reserves, or a decrease in required reserves.

How is reserve supply related to the spread s between the overnight rate and the expected overnight bond yield? Setting $R^* = R^S$ and $i = \hat{i}$, expression (8) determines banks' demanded bondholding B^* given s and the degree of uncertainty about the overnight bond yield as described by the distribution of ε relative to P. The market-clearing value for s must then depend on conditions governing the supply of bonds to banks, which is to say the behavior of nonbank bondholders. Under reasonable assumptions about nonbanks' bond demand, an increase in reserve supply would tend to reduce the market-clearing spread if it boosted banks' demand for bonds at a given spread, and a given degree of uncertainty about the bond yield. In the conventional view of interest-rate determination, an increase in reserve supply does *not* tend to reduce term premiums. This model would thus be inconsistent with the conventional view if it implied a generally positive relation between R^S and B^*, other things equal. Differentiating (8) holding fixed s, P and the distribution for ε (the expected bond price is thus scaled to today's overnight rate as $P^e_{+1} = (1+i+s)\,P$) gives:

$$\frac{\partial B^*}{\partial R^S} = -\left(\frac{\partial^2 V}{\partial B\,\partial R} + \frac{\partial^2 V}{\partial B\,\partial i}\,\frac{\partial \hat{i}}{\partial R^S}\right)\Bigg/\frac{\partial^2 V}{\partial B^2} \tag{12}$$

where:

$$\frac{\partial^2 V}{\partial B\,\partial R} + \frac{\partial^2 V}{\partial B\,\partial i}\,\frac{\partial \hat{i}}{\partial R^S} = \tag{13}$$

$$\frac{\lambda}{B^2}\Bigg[\; -f_P\{X_1\}\left(\hat{i} - \rho\,F_D\{-(R^S - RR)\} - (A - R^S)\tfrac{\partial \hat{i}}{\partial R^S}\right)\left((1+\hat{i})A - D - \hat{i}R^S - \rho\,F_D\{-(R^S - RR)\}\right)$$

$$-\,f_P\{X_1\}\,\rho^2\,(1 - F_D\{-(R^S - RR)\})\,F_D\{-(R^S - RR)\}$$

$$+\int_{\underline{\delta}}^{-(R^S-RR)} \left(f_P\{X_2\} - f_P\{X_1\}\right)\left(\rho - \hat{i} + (A - R^S)\tfrac{\partial \hat{i}}{\partial R^S}\right)\left((1+\hat{i})A - D - \hat{i}R^S - \rho(-(R^S - RR - \delta))\right) f_D\{\delta\}\,d\delta\Bigg]$$

$\frac{\partial^2 V}{\partial B^2}$ is negative by second-order conditions, while (13) is negative if possible reserve deficiency costs are small relative to bank capital and uncertainty about bond values (because $f_P\{X_1\}$ is approximately equal to $f_P\{X_2\}$ for any possible value of δ, so that the last line of the expression is close to zero). Thus $\frac{\partial B^*}{\partial R^S}$ is *negative* for parameter values that would generate expression (10). That is to say, under the conditions that match conventional models of overnight-rate determination, banks' demand for bonds is *reduced* by an increase in reserve supply. This is because the resulting decrease in the overnight rate and (holding the spread fixed) expected bond return tends to weaken tomorrow's capital position, increasing the probability of a capital shortfall. That prompts the bank to shift away from bonds, toward overnight lending.

3.4 When the overnight rate is zero

Now suppose that $R^S - RR \geq (-\underline{\delta})$: free reserve supply is great enough to eliminate the danger of a reserve deficiency. From (9), today's overnight rate must be zero. With no return to overnight lending, a bank chooses R and B subject to $A = P\,B + R$, the spread s is equivalent to the expected return to bonds so $s = \frac{P^e_{+1}}{P} - 1$, and:

$$V = A - D + (P^e_{+1}/P - 1)(A - R) - \lambda \int_{-P^e_{+1}}^{X_1} -\left(A - D + (P^e_{+1}/P - 1)(A - R) + \left(\tfrac{A-R}{P}\right)\varepsilon\right) f_P\{\varepsilon\}\, d\varepsilon \qquad (14)$$

$$\text{where } X_1 = -P^e_{+1} + P\left(1 - \tfrac{A-D}{A-R}\right)$$

The optimal reserve R^* satisfies the first-order condition:

$$0 = -\left(P^e_{+1}/P - 1\right) - \lambda\, F_P\{X_1\}\left(\left(P^e_{+1}/P - 1\right) + \tfrac{1}{P} E\left[\,\varepsilon \,|\, \varepsilon < X_1\,\right]\right) \qquad (15)$$

Expression (15) defines the bank's demand for reserves: R^* just balances the expected overnight bond yield against the value of a marginal reserve dollar in reducing the probability of a capital shortfall.

The equilibrium bond price $\hat{P}$ must be such that R^* equals reserve supply R^S. Assuming that the overnight rate was zero yesterday, R^S is also equal to the bank's initial cash balance so $A = P\,B_{-1} + R^S$. Rearranging (15) and making substitutions into X_1 gives:

$$\tfrac{P^e_{+1}}{\hat{P}} - 1 = \frac{\lambda F_P\{X_1\}}{1+\lambda F_P\{X_1\}} \frac{\left(-E[\varepsilon\,|\,\varepsilon < X_1]\right)}{\hat{P}} \quad \text{where } X_1 = -P^e_{+1} + \tfrac{D-R^S}{B_{-1}} \tag{16}$$

or:

$$\hat{P} = P^e_{+1} + \left(\frac{\lambda F_P\{X_1\}}{1+\lambda F_P\{X_1\}}\right) E[\varepsilon\,|\,\varepsilon < X_1] \tag{17}$$

Expression (17) is a relation between reserve supply and today's bond price that must hold whatever the conditions governing the supply of bonds to banks. Note that the required reserve *RR* does *not* enter into (17). It is the supply of reserves R^S rather than *free* reserves $R^S - RR$ that is related to the bond price when the overnight rate has been driven to zero.

Changes in expectations about future overnight rates or future term premiums correspond to changes in expectations about tomorrow's bond price. Their effects on today's bond price are potentially quite complicated, since the distribution for ε would generally change along with revisions to the expected bond price P^e_{+1}. (As P^e_{+1} increases, for example, the distribution for ε would become less skewed to the right — the range of possible upside errors shortens relative to the range of possible downside errors.) But what relations hold for *given* expectations of future overnight rates and term premiums, that is holding fixed P^e_{+1} and the distribution for ε? Consider the effect of variations in reserve supply, possibly associated with variations in deposits. From (17):

$$\frac{\partial \hat{P}}{\partial R^S} = \left(1 - \frac{\partial D}{\partial R^S}\right) \left(-\frac{\partial^2 V}{\partial R^2} \Big/ \left.\frac{\partial^2 V}{\partial R\, \partial P}\right|_{R=R^*}\right) \tag{18}$$

$$= \left(1 - \frac{\partial D}{\partial R^S}\right) \left(-\frac{\partial^2 V}{\partial R^2} \Big/ \left(\frac{P^e_{+1}}{P^2} + \lambda F_P\{X_1\} \frac{P^e_{+1} + E\left[\varepsilon \mid \varepsilon < X_1\right]}{P^2}\right)\right)$$

The second-order condition that $\frac{\partial^2 V}{\partial R^2} < 0$ implies that (18) is positive as long as $0 \le \frac{\partial D}{\partial R^S} < 1$. That is to say, the bond price rises in response to an increase in reserve supply, as long as any associated increase in deposits is smaller than the increase in reserve supply. The bond price must rise to reduce the expected overnight yield, so that the bank is willing to hold more reserves and less bonds ($\Delta(P\,B) = \Delta A - \Delta R$).

3.5 Monetary policy when the overnight rate is zero

Possible actions of monetary authorities include changes in reserve requirements, which correspond to exogenous variations in required reserves *RR*; changes in the discount rate or other regulations affecting the cost of reserve deficiencies ρ ; and purchases or sales of assets such as bonds or foreign exchange, which alter the quantity of high-powered money. The first two actions do not affect the market bond price when the overnight rate is zero. The last, however, must affect reserve supply, unless the nonbank public simultaneously chooses an equal change in its holding of cash. A change in reserve supply must in turn affect the bond price unless nonbanks simultaneously choose an equal change in deposits. The shifts in nonbanks' demand for cash or deposits that would neutralize a change in high-powered money supply would be inconsistent with standard money demand relations. As noted above, such relations appear to have held in the 1930s, perhaps for reasons similar to those applied here to banks' reserve demand. But nonbanks' behavior is outside this model. By itself, the model can be taken to imply that a boost to high-powered money supply raises the bond price as long as it is accompanied by an increase in reserve quantity that exceeds any increase in deposits. Recall this is true *holding fixed* expectations of the future bond price, which is to say holding fixed expectations of future overnight rates and term premiums.

What if expectations are revised in response to a reserve supply shock or its effects, for example, in response to an observed change in today's bond price? That reinforces the effect of reserve supply *per se* as long as perceived possible values for tomorrow's bond price P_{+1} are revised in the same direction as the observed change in the bond price. Importantly, such a revision could be rational even if the reserve supply shock has *no* implications for future overnight rates. Consider a change in reserve supply that is likely to persist through tomorrow, but not long enough to affect the length of the period that the overnight rate will remain zero. A revision to beliefs about P_{+1} associated with this reserve supply shock would be confirmed by experience (expression (17) will hold tomorrow as well as today). At the same time, there is no reason to revise expectations of future overnight rates.

4. Interest rates and reserve quantities in the 1930s

4.1 The disappearance of overnight lending

An environment of zero overnight rates developed in the U.S. over the early 1930s, along with crises in domestic and international financial markets. The financial crises were largely resolved by the spring of 1934, following the inspection, reopening and recapitalization of banks in the months following March 1933 and, in January 1934, the introduction of Federal deposit insurance and the official devaluation of the dollar against gold (Friedman and Schwartz, 1963, pp. 420-83; Meltzer, 2003, pp. 415-59). But active markets for overnight instruments, with opportunities for banks to lend overnight at positive rates, did not reappear until after the outbreak of the Second World War.

Overnight fed funds rates fell sharply over the months following the stock market crash in October 1929, as the Federal Reserve cut discount rates, injected reserves through open-market operations, and refrained from sterilizing gold inflows. "The Market was in the midst of a veritable deluge of Federal Funds and demand had almost died away" (Turner, 1931, p. 47). Fed funds rates rose again in late 1931 and early 1932 as the Fed reversed course for a while, but by the end of 1932 rates had fallen again, as low as 13 basis points. Bank panics discouraged fed funds lending because they raised the perceived danger that borrowing banks would default, but the market failed to revive even after the reform of the banking system. From 1934 through early 1941 instances of fed funds lending were few and far between. This was not because lenders viewed fed funds loans as risky. Rather, "there were practically no occasions when there were borrowers in need" (Willis, 1957, p. 11; see also Westerfield, 1938, p. 621), except perhaps in late summer and fall of 1937, when Federal Reserve staff reported a short-lived pickup in borrowing (Federal Reserve Board, 1937, p. 820).

The call money market was not disrupted by the 1929 crash, as margins proved sufficient to protect lenders (Bradford, 1941, p. 444), but this market also died out by 1934. Figure 1 shows data on the volume of net borrowing on call by stock exchange brokers and dealers, and the official interest rate for new loans set by the New York stock exchange money desk. Unfortunately, the volume data were not collected after 1935, and the relation between the official call money rate and the market rate is unclear: even before 1934 the official rate was sometimes deliberately set above the market-clearing level, in which event "rates on the outside market" were lower (Beckhart, 1932b, p. 55). After 1934 the official rate was usually held fixed at one percentage point; according to contemporary observers there was no persistent demand for funds at this or any other rate (Bradford, 1941, p. 445; Turner, 1938, pp. 48, 89; Federal Reserve Board, 1936b, p. 31). One reason for the absence of borrowers may have been the imposition of Regulation T in October 1934, which set high minimum margin requirements for loans collateralized by stocks and bonds (Federal Reserve Board, 1936b, p. 32). But markets for repos and loans collateralized by government or government-guaranteed securities also remained moribund even though these were not subject to Regulation T (Federal Reserve Board, 1934a, p. 629), and banks appeared eager for opportunities to lend on such collateral (Ahearn, 1965, p. 48).

The rate for interbank demand deposits fell along with rates for open-market loans. From 1922 through 1929, the rate paid by New York Clearinghouse banks was never less than 2 percent. The rate was cut to zero by early 1933, months before interest on interbank demand deposits was banned by regulation (Homer, 1963, p. 376).

Standard models of reserve demand, as well as the model presented above, imply that when there is no return to overnight lending there should be almost no discount borrowing to cover reserve deficiencies. In the 1920s and 1930s, banks could take out discount loans for other reasons as well, including the resolution of longer-term financial difficulties. (The later distinction between adjustment credit and extended credit [Meulendyke, 1998, pp. 153-54], or today's difference between primary and secondary credit [Federal Reserve Board, 2002], did not exist.) Banks active in money markets, however, borrowed almost exclusively to cover unforeseen reserve drains (Riefler, 1930, pp. 31-32; United States Senate, 1931, Appendix Part 6, p. 792). Figure 2 shows discount borrowing by banks located in the money-market centers of New York City and Chicago, along with borrowing by all member banks. Borrowing was negligible after 1933 in the two cities and after 1934 for all banks, except for a slight rise in the fall of 1937. Thus, the volume of discount borrowing is consistent with a zero overnight rate for almost all of the 1934-39 period, certainly for 1934 through early 1937 and 1938-39. Also, the quantity of nonborrowed reserves — reserve balances *less* discount borrowing — should be close to the model's definition of reserve account balances, that is balances held before any borrowing to cover reserve deficiencies.

4.2 Monetary policy and longer-term interest rates 1934-39

In early 1934 the U.S. Treasury bought gold in foreign markets to enforce the devaluation of the dollar. By the end of March 1934, the dollar was trading freely at the official rate and active purchases of gold by the Treasury ceased (Johnson, 1939, pp. 43-45). In the following period from April 1934 to December 1936, the quantity of nonborrowed reserves increased about 85 percent. This was not a result of actions taken by the Federal Reserve. Until late in this period the Federal Reserve System took no policy actions at all, except for reductions in discount rates at some reserve banks, other than New York, in early 1935 (Meltzer, 2003, p. 491). Open-market purchases of securities for the system's account were undertaken only to replace maturing securities (Friedman and Schwartz, 1963, p. 511).

The growth in nonborrowed reserves instead resulted from operations of the Treasury: purchases of gold and silver from outside the U.S. and, to a much smaller degree, programs to purchase production of domestic mines. Purchases of foreign gold were passive, depending on the volume of foreign exchange offered at the fixed gold rate, except for some days in January, 1935 when the Treasury actively bought gold to fight an appreciation of the dollar (Blum, 1959, p. 129). The inflow of foreign exchange mainly reflected capital flight to the U.S. from political and economic disruptions in Europe and Asia (Romer, 1992, p. 759). According to Friedman and Schwartz (1963, p. 544) and Romer (1992, p. 773), the resulting trend growth in high-powered money was clearly a shock to money supply rather than a response to U.S. demand.

Short-term fluctuations in reserve growth around the 1934-36 trend were also caused by factors arguably exogenous to money demand. Purchases of domestic gold and silver took place at a fairly steady rate (judging from available data, which are monthly [Federal Reserve Board, 1943, Table 156]), but the foreign inflow was spurred or slowed by political events. It ceased altogether for the first months of 1936, then resumed in April (Federal Reserve Board, 1936b, pp. 8-11; 1936a, pp. 311-12). There were variable lags between gold purchases and the resulting increase in high-powered money supply, caused by the Treasury's management of payments and borrowing. A Treasury purchase of precious metal could be covered out of the Treasury's accounts at commercial banks or regular Treasury borrowing. High-powered money supply increased only after the Treasury created gold or silver certificates "backed" by the purchased metal, deposited the certificates in the Treasury's Federal Reserve account, and made payments out of that account. In the meantime, the value of purchased gold or silver appeared in the Treasury's books as an increment to Treasury balances held outside commercial banks, that is in the Treasury's Federal Reserve account or, before the creation of the gold or silver certificate, "Treasury cash" (Federal Reserve Board, 1943, p. 365). Apart from the effect of gold purchases, Treasury balances and hence high-powered money supply varied from week to week as a result of ordinary tax payments, spending and financing operations. (Nowadays the Federal Reserve adjusts its open-market operations to counteract such events. Treasury payments affect reserve supply, and hence overnight rates, only if they are unforeseen by the Fed [Hamilton, 1997]). In sum, the short-run effect of Treasury operations on reserve supply was not equal to the change in the value of the Treasury's gold stock; it was instead the change in the gold stock *less* the change in Treasury balances (Friedman and Schwartz, 1963, pp. 506-08).

On July 15, 1936, the Federal Reserve Board announced an upcoming change in policy: reserve requirements would be hiked as of the following August. The date of the announcement came as a surprise to the Treasury, at least (Blum, 1959, p. 356; Meltzer, 2003, p. 503). On January 30, 1937, the Fed again announced a future hike in reserve requirements, to become effective in two steps, in March and May 1937 (Eccles, 1951, p. 291). Meanwhile, the supply of high-powered money was affected by a change in Treasury policy. On December 21st, the Treasury announced it would sterilize gold inflows. It began to do so on December 24th, booking the value of "inactive" gold as an addition to Treasury cash (Johnson, 1939, p. 133). In adopting these policies, neither the Treasury nor the Federal Reserve intended to cause an increase in interest rates. Federal Reserve staff believed that changes in reserve supply or reserve requirements would have no direct effect on interest rates under the conditions prevailing in the 1930s (Goldenweiser, 1951, pp. 175-82; Calomiris and Wheelock, 1998). The goal of the policies was to make it easier for the Fed to tighten *in the future*. Fed policymakers seem to have ignored the possibility that current long-term rates would be affected by expectations of future tightening. Treasury authorities feared the hikes in reserve requirements would cause a rise in bond yields. Policymakers in both institutions agreed to buy bonds if yields rose (Blum, 1959, pp. 354-57).

In early 1937 the Fed and Treasury began to reverse course, taking steps to partly counteract the effect on free reserves of the scheduled hikes in reserve requirements. In March 1937 the Treasury bought bonds; on April 5th the Fed announced it would buy bonds to increase the size of its portfolio for the first time since 1933 (Blum, 1959, pp. 369-75; Gordon and Wescott, 1938, p. 107). In September 1937 the Fed announced it had authorized more purchases of government debt "for the continuation of the System's policy of monetary ease" (Blum, 1959, p. 378). Purchases began the following month (Crum, Gordon and Wescott, 1938a, p. 49). Also in September 1937, the Treasury announced it would release part of its stock of "inactive" gold into the reserve supply (Johnson, 1939, p. 137). On February 14, 1938, the Treasury announced that a limited volume of current gold inflow would be passed through to reserves (Crum, Gordon and Wescott, 1938b, p. 93). On April

14, 1938, President Roosevelt announced that *all* of the Treasury's stock of inactive gold and *all* future inflows would be released into reserve supply, and reserve requirements would be reduced immediately (Crum, Gordon and Wescott, 1938b, p. 94; Blum, 1959, p. 425). The following week the Treasury further specified the mechanisms for releasing inactive gold "thereby increasing member bank reserves" (Federal Reserve Board, 1938a, pp. 343-44).

From that time through the outbreak of the Second World War in August 1939, high-powered money again grew rapidly. Foreign gold inflows had ceased in late 1937, in response to rumors that the Roosevelt administration was planning another dollar devaluation, but they resumed at the time of the Munich crisis in September 1938 (Friedman and Schwartz, 1963, p. 509). According to Friedman and Schwartz (1963), "Munich and the outbreak of war in Europe were the main factors determining the U.S. money stock in those years, as Hitler and the gold miners had been in 1934 to 1936" (p. 545; see also Romer, 1992, p. 774). For this period, however, one cannot be sure that short-term fluctuations in reserve growth were exogenous in the sense they had been over 1934-36. The Federal Reserve was no longer refraining from open-market operations, and the Treasury was no longer ignoring the affect of its operations on interest rates and reserves. Now both institutions were attempting to "smooth" Treasury bond yields and maintain "orderly" markets, by selling bonds against decreases in yields and buying bonds against increases (Meltzer, 2003, pp. 506, 510, 512, 517 n. 209, 533, 533 n. 245, 546, 549).

Figure 3 plots data on reserve quantities from April 1934 through 1939 at the shortest available frequency. Weekly data are available for nonborrowed reserves ("Nonborrowed"), required reserves ("Required"), the value of the Treasury's gold stock at the official price ("U.S. gold stock"), and Treasury balances held outside commercial banks ("Treasury balances," equal to the sum of the Treasury's Federal Reserve accounts and Treasury cash). Changes in reserve requirements are marked by discrete jumps in required reserves. Vertical lines mark the week when the Treasury began to sterilize gold inflows and the week when the Treasury began to release sterilized gold. The buildup in "inactive" gold between these weeks appears in Treasury balances. Outside those weeks, there is an obvious short-term relation between the gold stock, fluctuations in Treasury balances and nonborrowed reserves.

What about the broader notion of bank reserves, that is, nonborrowed reserves *plus* vault cash? Unfortunately, most banks reported vault cash and other balance sheet information for no more than four days a year (call report dates). But a subset of Federal Reserve member banks — "weekly reporters" — reported such data every week (Federal Reserve Board, 1943, p. 127). Friedman and Schwartz (1970) extrapolated weekly reporters' data to create a monthly estimate of all banks' vault cash (pp. 378-79). The line labelled "Nonborrowed plus vault cash" plots the sum of that estimate and monthly average nonborrowed reserves. Judging from this estimate, movements in nonborrowed reserves *plus* vault cash were highly correlated with nonborrowed reserves alone.

Table 1 shows results of regressions that indicate the relation between week-to-week changes in nonborrowed reserves, Treasury gold purchases and Treasury balances. The samples for the regressions were divided into two periods: the weeks before the Fed's July 1936 announcement of upcoming required reserve hikes, and later weeks. The left-hand side variable in the regressions was the week-to-week change in nonborrowed reserves. For columns (1), the right-hand side variable (along with a constant) was the change in the Treasury gold stock. For columns (2), the right-hand side variable was the change in the Treasury gold stock *minus* the change in Treasury balances. For 1934-36, the change in the gold stock gives a coefficient considerably less than one, with a high standard error and a low R^2, but the gold stock net of Treasury balances gives a coefficient practically equal to one and an R^2 of 92 percent. That shows gold flows by themselves were not immediately related to reserve supply, but the net effects of Treasury gold purchases and changes in Treasury balances were entirely unsterilized and accounted for the bulk of week-to-week changes in nonborrowed reserves over 1934-36. For the later period, the estimated coefficient on gold inflow net of Treasury balances is less than one and the R^2 is 78 percent, indicating that the reserve effects of these factors were partially (or sometimes) sterilized, and accounted for less of the week-to-week changes in reserves.

Table 2 shows results of regressions that indicate the relation between week-to-week changes in nonborrowed reserve supply to all banks — the same variable used for Table 1 and Figure 3 — and balance sheet items for the particular set of banks that reported weekly. For each specification the right-hand side variable (along with a constant) was the change in the log of nonborrowed reserve supply to all banks. For specification (1) the left-hand side variable was the change in the log of weekly reporters' own nonborrowed reserves *plus* vault cash. The estimated coefficient is very close to one, indicating that changes in total nonborrowed reserve supply were nearly equivalent to changes in the broader notion of reserves for this set of banks. For specification (2) the left-hand side variable was weekly reporters' deposits *less* the sum of their nonborrowed reserves and vault cash. (The sample for this regression begins in September 1934, as the deposit data do not stretch back before that.) For (3) the left-hand side variable was the change in the log of the value of bondholdings (both government and corporate bonds) reported by the banks. This was book value rather than market value (Federal Reserve Board, 1943, p. 67), so it probably indicates the effects of bond sales and purchases, rather than the total effect on bond portfolios of purchases, sales, and changes in bond prices. Estimated coefficients in both specifications are negative and significantly different from zero. Thus, for this set of banks at least, changes in nonborrowed reserve supply were associated with changes in deposits, but the changes in deposits were smaller than the changes in reserves, so increases in nonborrowed reserve supply were associated with sales of bonds (or reductions in bond purchases).

Interest rates on Treasury debt and corporate bonds over the 1934-39 period are plotted in Figure 4. The lines labelled "Treasury bills" plot weekly auction discount rates for new issues, the maturity of which varied over the period. "Treasury 3-5 year notes" plots an index of yields to maturity on medium-term debt. "Treasury bonds" is an index for long-term bonds (due or callable after 12 years). "Corporate bonds" is an index of high-grade corporate bond yields. The obvious spike in all rates occurring in late 1939 marks the announcement of a treaty between Britain and Poland in the last week of August. This was viewed as greatly increasing the probability of war. German forces invaded Poland on the morning of September 1.

The figure shows that yields on Treasury bills remained very low from April 1934 through December 1936, while medium-term note yields fell from over two percent to one percent and Treasury bond yields fell about fifty basis points. At the end of December 1936, Treasury bill rates and note yields rose sharply, followed by long-term Treasury bonds. By early May 1937, bill rates had climbed to 70 basis points from about 10 basis points in early December 1936, while notes were over one and a half percent. Yields turned down again in September 1937. By mid-1939 medium-term note yields were lower than fifty basis points and bill rates were practically zero.[3] Meanwhile, corporate bond yields moved along with Treasury bonds, as variations in Treasury yields dominated changes in the corporate-Treasury spread. The magnitude of the swings in bond yields between April 1934 and July 1939 — almost two percentage points from high to low for 3-5 year notes — is comparable to swings around postwar changes in monetary policy. In the late 1980s, for example, 5-year Treasury yields ranged from lows around 7.7 percent in 1988 to highs around 9.5 percent in 1989; in the late 1990s, 5-year yields ranged from about 4.2 percent in 1998 to 6.7 percent in 2000 (on a monthly average basis; data from Federal Reserve Board website).

Figures 3 and 4 together show an obvious relation between interest rates and the big swings in reserve quantities caused by turns in monetary policy over 1934-39. Yields to maturity fell over 1934-36, as policy allowed rapid growth in nonborrowed reserves. Bond yields rose after the end of 1936, as the Treasury sterilized gold and reserve growth ceased. Bond yields fell after September 1937 as policy again allowed rapid reserve growth. The relation is also apparent in Figure 5, which scatters Treasury bond yields against the log of nonborrowed reserves. Special symbols mark the weeks from the Federal Reserve's July 1936 announcement of an upcoming hike in reserve requirements, through the April 1938 announcements of reductions in reserve requirements and complete de-sterilization of Treasury gold. This 1936-38 period contains all of the obvious announcements about monetary policy described above. Observe that these weeks appear as disturbances to a negative relation between bond yields and nonborrowed reserves that prevailed *before and after* the 1936-38 period.

4.3 Possible explanations of interest-rate movements over 1934-39

The current view of liquidity traps, which assumes that reserve demand is indeterminate once the overnight rate has been drive to zero, could explain the apparent

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[3] At times Treasury bill discount rates were actually negative. This could occur because Treasury debt was exempt from some personal property taxes (Morrison, 1966, p. 30) and gave the purchaser a valuable option to purchase long-term bonds in the future (Turner, 1938, p. 58). Stephen Cecchetti (1988) presents estimates of true yields on U.S. Treasury debt accounting for the value of these options. The estimates suggest that true yields on three-month Treasuries were always positive, though they were as low as five basis points for a number of months in late 1938 and early 1939 (Table A1). In this paper I rely on the raw data because Cecchetti's figures cover just one week in every month.

relation between bond yields and reserve quantity over 1934-39 as a result of coincidence between changes in reserve supply and news that changed expectations of future overnight rates. Conceivably, changes in reserve quantities themselves constituted news about future overnight rates, because they were expected to persist long enough to lengthen the horizon of the zero-rate regime or depress the level of future positive overnight rates (as in the model of Auerbach and Obstfeld 2003). The particular reserve quantity most obviously relevant for expectations of future overnight rates would be free reserves. Another possibility consistent with the current view of liquidity traps is that some factor related to term premiums coincidentally caused changes in reserve supply. In particular, one might argue that increases in foreign demand for U.S. assets tended to reduce U.S. term premiums, while they boosted reserve growth through the effect of foreign exchange inflows on the monetized gold stock. In that case bond yields would be less closely related to reserves than to changes in the Treasury gold stock, which was more directly linked to foreign asset purchases.

The view of reserve demand presented in this paper suggests that movements in bond yields over 1934-39 were at least partly, and perhaps mostly *caused* by the associated changes in reserve quantity. First, reserve supply could affect bond yields for given expectations of future bond yields. Second — and as a consequence of the first point — reserve supply shocks could force changes in expected future bond yields for given expectations of future overnight rates.

How can one judge between the different explanations of 1930s developments? Certainly, many changes in reserve supply growth over the 1930s were accompanied by announcements of changes in Treasury or Federal Reserve policy, while contemporary discussions of financial markets often mentioned possible links between policy announcements, changes in expectations and bond prices.[4] At the same time, statements of

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[4] Examples include *Business Week* (1936), Gordon and Wescott (1937, p. 106), Currie (1980, p. 328). In a *New York Times* article of 1935, a banker observed that "The low rate for money itself engenders some opposition and perhaps unconsciously brings pressure for restrictive measures in the hope of higher money rates and thus of higher bank earnings," but asserted that continued low interest rates were essential to economic recovery, and warned that "any restrictive measures which were to be taken at this stage by the Federal Reserve authorities, whether by raising reserve requirements or by letting government securities run off [decreasing nonborrowed reserve supply], might be construed as a reversal of the cheap money policy which has been pursued since the days of the bank holiday" (Gilbert, 1935).

1930s observers are consistent with the notion that banks had a definite demand for reserves and actively managed the margin between reserves and bonds. According to the Annual Report of the Federal Reserve Board for 1937 (see also Bradford, 1941, p. 447):

> In recent years the bond market has become a much more important segment of the open money market, and banks, particularly money market banks, to an increasing extent use their bond portfolios as a means of adjusting their cash position to meet demands upon them. At times when the demands increase they tend to reduce their bond portfolios and at times when surplus funds are large they are likely to expand them. (Federal Reserve Board, 1938b, p. 7)

Robinson (1940) observes:

> In former periods call loans were favorite ... assets among banks. Now the market supplies of these loans and of most forms of secondary reserve except Treasury short-term securities are greatly reduced. Bank liquidity has nevertheless increased in recent years since cash reserves are currently so much in excess of legal requirements. Excess reserves have become a kind of substitute for the call loan. (p. 178)

Fortunately, some distinct or at least specific implications of the view presented in this paper can be tested with available data on bond yields and reserve quantities. Week-to-week changes in bond yields should have been negatively correlated with week-to-week changes in reserves whether or not they coincided with monetary policy announcements. The relation should hold controlling for the change in the gold stock. Bond yields should appear specifically related to *nonborrowed* reserves rather than free reserves — controlling for nonborrowed reserves, changes in required reserves should not matter. Finally, the relation between bond yields and nonborrowed reserves should have been *weaker* for bonds of *longer* maturity. This is because, according to the model, the effect of reserve supply on a bond's price reflects a relation between reserve supply and the bond's expected overnight yield. A given change in expected overnight yield has a smaller effect on a longer bond's yield to maturity, so it should show a weaker effect of reserve supply shocks. The current view of liquidity traps might or might not predict this pattern, depending on the significance of news for the path of overnight rates in the near future *versus* the more distant future.

5. Relations between week-to-week movements in bond yields and reserve quantities

5.1 Tests to be performed

I regress week-to-week changes in yields to maturity on Treasury medium-term notes, and long-term bonds, on week-to-week changes in nonborrowed reserves, required reserves, and the Treasury gold stock. For one set of regressions the sample includes all weeks from mid-April 1934 through early August 1939 (stopping before the announcement of the British-Polish treaty). For another set, the sample is edited to exclude two weeks around dates of announcements (the week containing the date and the following week) by the Treasury, Federal Reserve or President that could be taken to indicate a current or upcoming change in monetary policy such as planned changes in reserve requirements, sterilization of foreign exchange inflows, bond purchases or sales by the Federal Reserve or Treasury. The results of these regressions will show whether the relation between yields and reserves apparent in Figure 5 can be accounted for by coincidence between reserve growth and gold inflows or obvious news about monetary policy.

For the last set of regressions, the sample includes *only* weeks from April 1934 through the beginning of July 1936. This period represents a unique natural experiment. It is free of changes in reserve requirements, announcements of *future* changes in reserve requirements, or other announcements obviously related to monetary policy. Within it, neither the Federal Reserve nor the Treasury attempted to influence bond yields or sterilize effects on nonborrowed reserves of Treasury gold purchases and Treasury payments. Arguably, shocks to nonborrowed reserve supply caused by the interaction of gold purchases and Treasury payments were accidental, unrelated to news about monetary policy, and hence unlikely to have influenced long-term rates through expectations of future overnight rates.

5.2 1934-39

Table 3, panel A shows results of regressions using the 1934-39 sample. A constant, time and time-squared were included on the right-hand side of the regressions to control for any accidental relation between trends in bond yields and reserve growth. Excluding them gave similar estimated coefficients on reserve quantities.

Results for medium-term notes are in the first set of columns. In column (a), the change in log nonborrowed reserves is alone on the right-hand side (along with time trends). The estimated coefficient is negative and significantly different from zero at conventional levels. In column (b) the change in nonborrowed reserves is replaced by the change in free reserves. This gives a smaller coefficient and a larger standard error than the coefficient on nonborrowed reserves in column (a). For (c), both the change in nonborrowed reserves and the change in required reserves are included on the right-hand side. The coefficient on required reserves is not significantly different from zero, while the coefficient on nonborrowed reserves is about the same as in column (a). For (d), the change in the gold stock is included along with the change in nonborrowed reserves. The coefficient on nonborrowed reserves remains significant, while the coefficient on the gold stock is not significantly different from zero. Results for long-term Treasury bonds are shown in the second set of columns. The estimated coefficients are of the same sign as those for notes, but smaller in magnitude.

Panel B of Table 3 shows results when the sample excludes weeks around monetary policy announcements. The table lists the weeks so identified. Excluding these weeks has little effect on the results. Coefficients on nonborrowed reserves are still negative and significantly different from zero. Coefficients on required reserves and gold are not significantly different from zero. Coefficients for long-term bonds are smaller than for medium-term notes.

5.3 1934-July 1936

Table 4 shows results for the 1934-36 period. Results for medium-term notes are again in the first set of columns. The estimated coefficient on nonborrowed reserves alone, shown in column (a), is negative and significantly different from zero at the one percent level. The change in required reserves, added to the right-hand side for column (b), gives an estimated coefficient that is not significantly different from zero (and actually has a negative sign). For (c) the change in the gold stock was included on the right-hand side along with nonborrowed reserves. The coefficient on the gold inflow is not significantly different from zero, while the coefficient on nonborrowed reserves is about the same as in column (a). For column (d), the right-hand side variable is the change in log nonborrowed reserves caused by the sum of Treasury gold purchases and the change in Treasury balances (as described in the table). The estimated coefficient on this variable is negative, significantly different from zero, and similar in magnitude to the coefficient on nonborrowed reserves in column (a). Results for long-term bonds are shown in the second set of columns. As in Table 3, coefficients on reserve quantities are of the same sign but smaller magnitude as those for medium-term notes.

5.4 Summary of results

The results of the regressions are consistent with the view of liquidity traps presented in this paper. Weekly changes in bond yields are negatively related to changes in nonborrowed reserves, but unrelated to changes in required reserves. The relation between bond yields and nonborrowed reserves remains after excluding weeks affected by obvious announcements about monetary policy, and after controlling for changes in the gold stock. It is weaker for bonds of longer maturity. It holds within the special period from 1934 through July 1936, not only for changes in nonborrowed reserves but for the portion of nonborrowed reserve growth caused by the interaction of Treasury gold purchases and the timing of Treasury payments.

The magnitude of the estimated coefficients implies that an eight-five percent increase in nonborrowed reserves, like the one that occurred from April 1934 to early December 1936, would be associated with a reduction of about 40 basis points in the medium-term yield to maturity. The actual decline in yield over that period was greater, about one percent. That makes sense assuming that the actual decline reflected changes in expectations of future bond prices as well as the effect of reserve supply *per se.* Changes in expectations from one week to the next would have been correlated with the weekly change in reserve supply, but not perfectly.

6. Conclusion

This paper has found that bond yields were negatively related to nonborrowed reserve supply over the period of zero overnight rates in the U.S. 1930s, even when the changes in reserve supply reflected transient factors that were unrelated to changes in monetary policy and arguably unlikely to have affected expectations of future overnight rates. At the same time, bond yields appear unrelated to changes in required reserves apart from news about monetary policy. That is what one would expect if the relation between bond yields and reserve supply reflected banks' demand for cash as an asset free of interest-rate risk.

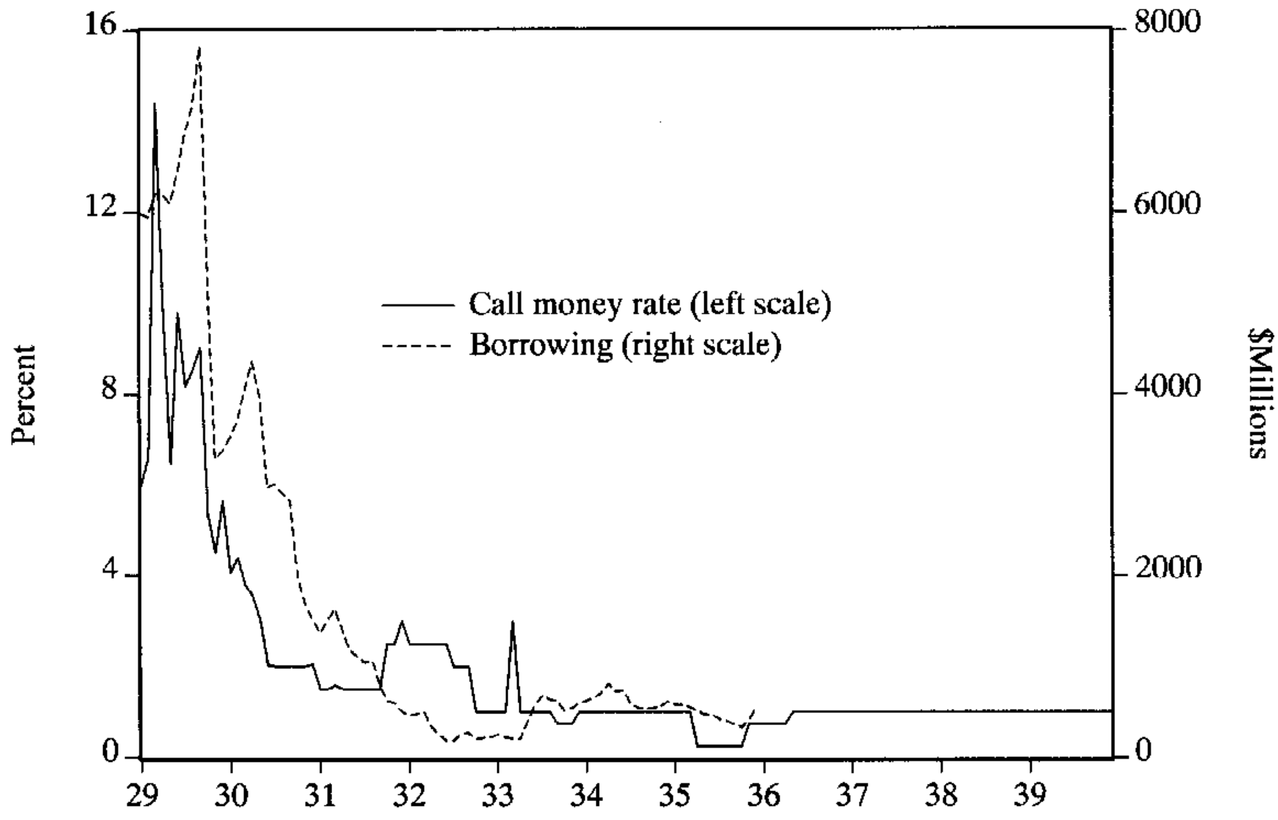
This paper has implications for the economic history of the 1930s. Many discussions of post-1933 monetary policy focus on the reserve requirement changes of 1936-38 (for example Cole and Ohanian, 1999, p. 8; Meltzer, 2003, pp. 518-21). Romer (1990) observes that short-term rates were already extremely low by 1933, and argues that the transmission mechanism of monetary policy over 1934-39 must have been something other than the interest-rate channel (p. 775). This paper implies that the reserve requirement changes did not matter (agreeing with Calomiris and Wheelock, 1996) except for possible effects on expectations, but interest rates *were* affected by policies determining nonborrowed reserve supply, such as gold sterilization. It is beyond the scope of this paper to assess the influence of nominal interest rates *versus* other factors (including non-interest rate channels of monetary policy) on the path of real activity over the 1930s, but it is worth pointing out the hike in interest rates coincident with the beginning of gold sterilization in December 1936 was followed by a business-cycle downturn in May, 1937 (as dated by the National Bureau of Economic Research cyclical peak). That is quite consistent with today's textbook rule of thumb that economic activity is affected by a change in monetary policy "about six months after it is made" (Mankiw, 2003, p. 382). There were, however, many other events in 1937 that could be blamed for the downturn (Currie, 1938; Meltzer, 2003, pp. 521-22).

The findings of this paper are also relevant to current debates about the conduct of monetary policy under low inflation. They contradict the view that the interest-rate channel of monetary policy is blocked as soon as short-term rates have been driven to zero, unless the central bank can manipulate expectations of future overnight rates. They imply that a central bank could enforce a decrease in longer-term rates in the face of stubborn expectations about future overnight rates, by boosting reserve supply through open-market operations in foreign exchange or long-term government bonds — assets that are already in the portfolios of most central banks.

Figure 1

NYSE official call money rate (new loans)
Net borrowing at call by NYSE brokers and dealers
January 1929 - December 1939

Monthly, figures for last week in month

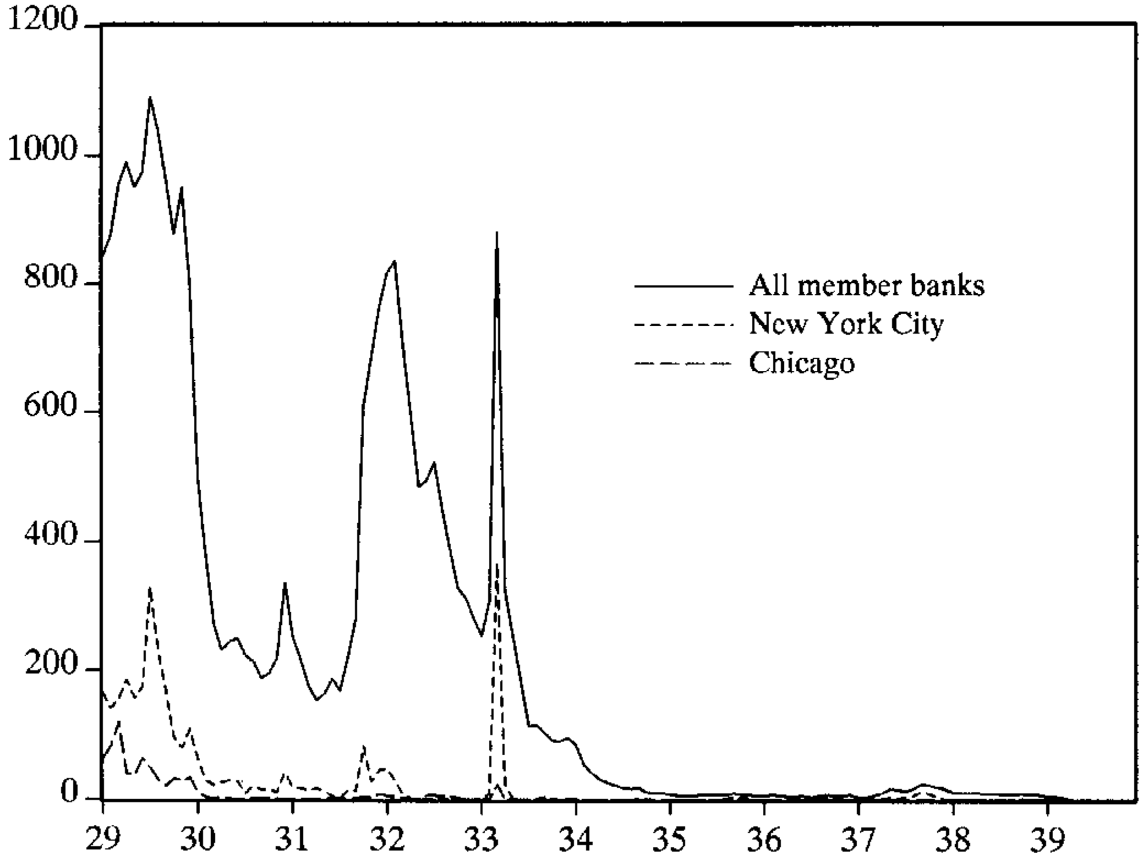


Sources: Borrowing from Federal Reserve Board (1931, 1934, 1936).
Rate from Federal Reserve Board (1943), Table 121.

Figure 2

Discount Borrowing
January 1929 - December 1939, Monthly

Average of daily figures

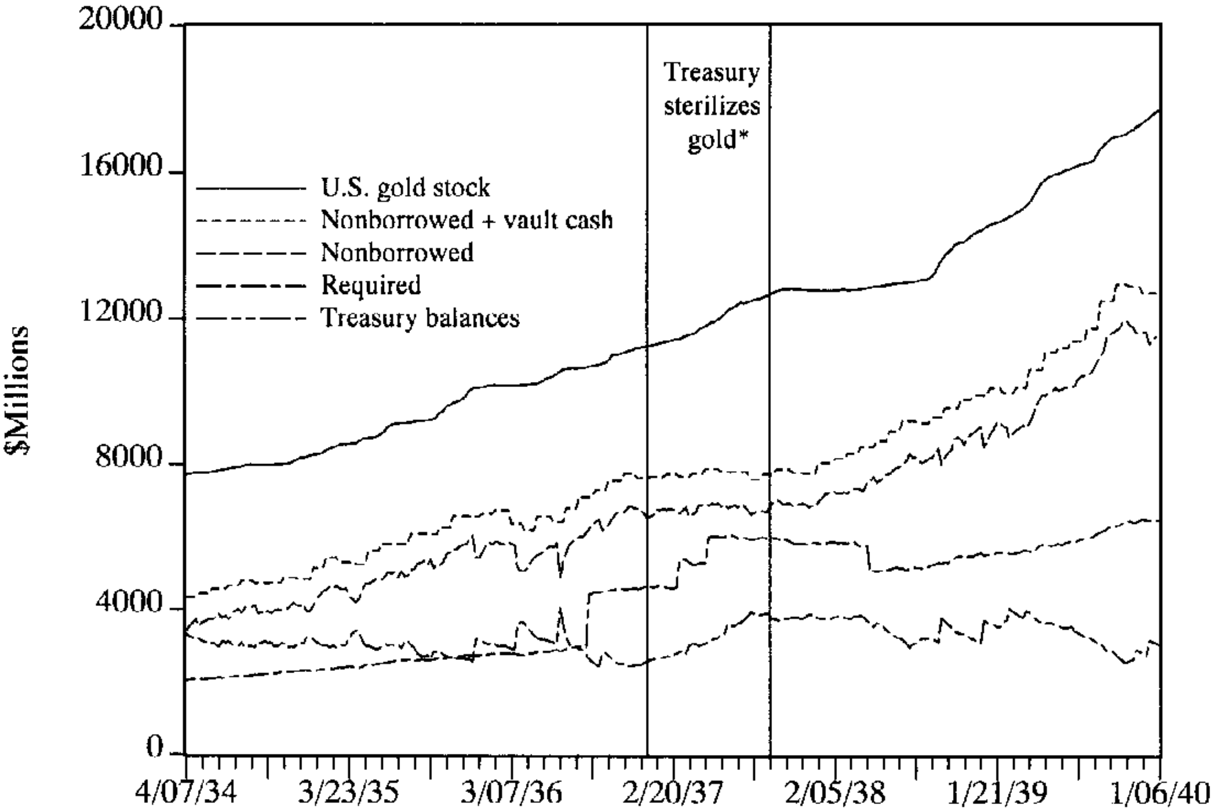


Source: Federal Reserve Board (1941), Table 105.

Figure 3

Reserves, Gold, and Treasury balances
April 1934 - December 1939

Weekly, Wednesdays (except Nonborrowed + Vault Cash, Monthly Estimate)



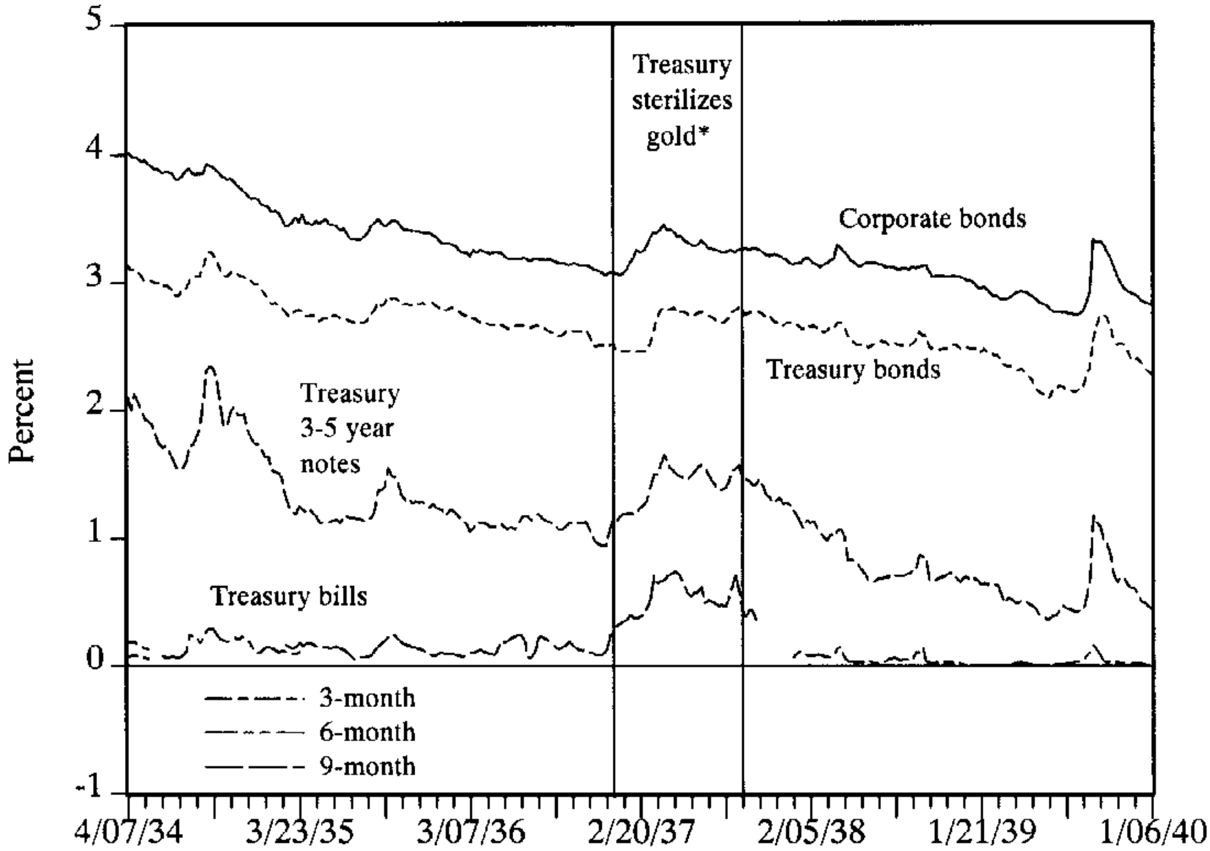
* Week ending December 26, 1936 through week ending September 18, 1937.

Sources: Federal Reserve Board (1943), Table 103; Friedman and Schwartz (1970), Table 25.

Figure 4

Interest rates
April 1934 - December 1939

Weekly, average of daily ending Saturday or auction rate



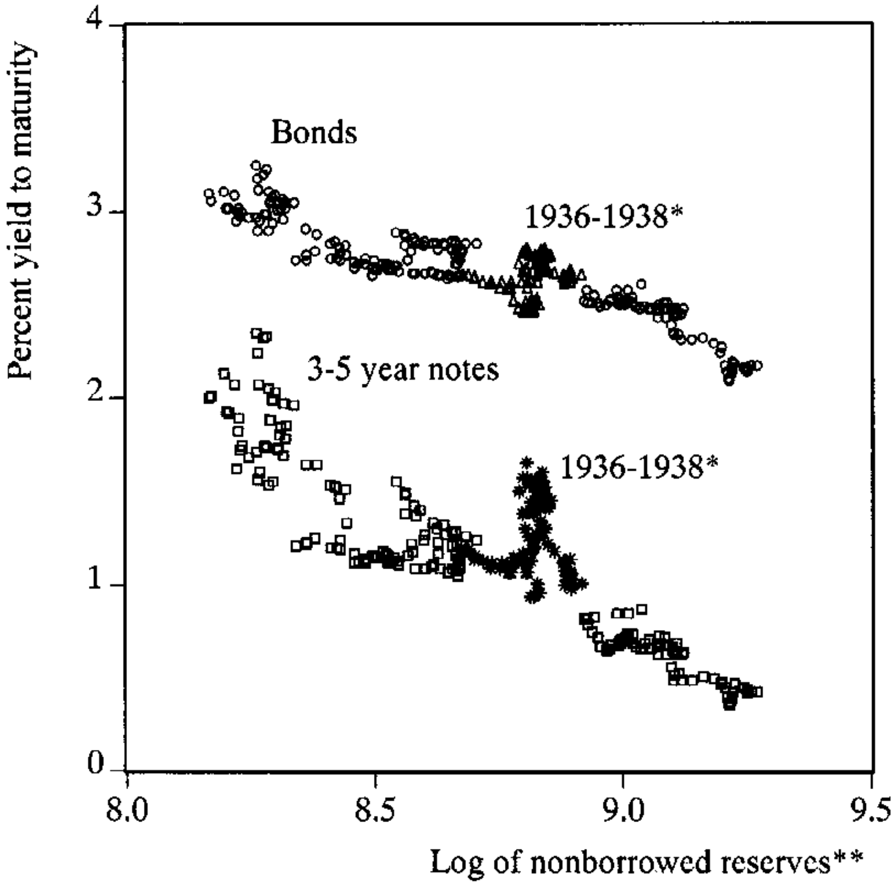
*Week ending December 26, 1936 through week ending Septmber 18, 1937

Source: Federal Reserve Board (1943), Tables 123, 129.

Figure 5

Nonborrowed reserves and Bond Yields
April 1934 - August 1939

Weekly, Wednesdays or average of daily ending Saturday



* Week ending July 18, 1936 through week ending April 16, 1938.
**Nonborrowed reserves = member bank reserves - duscount borrowing.

Source: Federal Reserve Board (1943), Tables 103, 123, 129.

Table 1

Week-to-week changes in nonborrowed reserves, gold and Treasury balances
April 1934-August 1939

All data $billions, Wednesday, change from previous week

R	Nonborrowed reserves
G	Value of U.S. gold stock (held by the Treasury)
TB	Treasury balances (balance in accounts at Federal Reserve banks plus Treasury vault cash)

Specification: (1) $\Delta R = Constant + \beta\Delta G + \varepsilon$

(2) $\Delta R = Constant + \beta(\Delta G - \Delta TB) + \varepsilon$

Estimated coefficient
[SE]
p-value

Period:	April 1934-July 1936* (117 observations)		July 1936-August 1939* (162 observations)	
Specification:	(1)	(2)	(1)	(2)
Gold	0.669 [0.542] *0.20*		0.558 [0.235] *0.02*	
Gold minus Treasury Balance		0.994 [0.028] *0.00*		0.924 [0.038] *0.00*
R^2	0.01	0.92	0.03	0.78

* Week ending April 21, 1934 through week ending July 11, 1936.
** Week ending July 18, 1936 through week ending August 19, 1939.

Source: Federal Reserve Board 1943, Table 103.

Table 2

Week-to-week changes in nonborrowed reserves
and weekly reporting banks' vault cash, deposits and bondholdings
April 1934-August 1939*

All data $billions, Wednesday, change from previous week

r Log of nonborrowed reserves, all member banks
$Ln\,(R + VC)$ Log of (nonborrowed reserves + vault cash), weekly reporting banks
$Ln(D - R - VC)$ Log of (deposits - nonborrowed reserves - vault cash), weekly reporting banks.
b Log of value of bondholdings, weekly reporting banks

Specifications: (1) $\Delta Ln\,(R + VC) = Constant + \beta\,\Delta r + \varepsilon$
(2) $\Delta Ln(D - R - VC) = Constant + \beta\Delta r + \varepsilon$
(3) $\Delta b = Constant + \beta\,\Delta r + \varepsilon$

Estimated coefficient
[SE]
p-value

	Left-hand side variable : log of		
	Reserves + vault cash (279 observations)	Deposits - (reserves + vault cash) (258 observations)	Bondholding (279 observations)
Specification:	(1)	(2)	(3)
Nonborrowed reserves *(all banks)*	1.070 [0.020] *0.00*	-0.096 [0.040] *0.02*	-0.193 [0.038] *0.00*
R^2	0.91	0.02	0.08

*Week of April 21, 1934 through week of August 19, 1939, except for column 2 for which sample begins September 15, 1934.

Source: All banks' nonborrowed reserves from Federal Reserve Board 1943, Table 103. Nonborrowed reserves is "member bank reserve balances" *minus* "bills discounted." Weekly reporting bank data from Table 48. Deposits is sum of demand deposits, including deposits due to U.S. government and other banks, and time deposits. Nonborrowed reserves for weekly reporters is "reserves with Federal Reserve banks" less "borrowings." Value of bondholding is "Investments, Total" including government and nongovernment securities.

Table 3

Week-to-week changes in Treasury yields and reserve quantities
April 1934-August 1939*

i Bond yield to maturity (average of days ending Saturday)
r Log of nonborrowed reserves (Wednesday)
rr Log of required reserves (Wednesday)
$Ln(R - RR)$ Log of free reserves (nonborrowed - required)
g Log of gold stock (Wednesday)

Specifications: (a) $\Delta i = Constant + \beta_T Time + \beta_{T2} Time^2 + \beta_r \Delta r + \varepsilon$

(b) $\Delta i = Constant + \beta_T Time + \beta_{T2} Time^2 + \beta_{free} \Delta free + \varepsilon$

(c) $\Delta i = Constant + \beta_T Time + \beta_{T2} Time^2 + \beta_r \Delta r + \beta_{rr} \Delta rr + \varepsilon$

(d) $\Delta i = Constant + \beta_T Time + \beta_{T2} Time^2 + \beta_r \Delta r + \beta_g \Delta g + \varepsilon$

Table 3 (cont.)

A) Including all weeks — Estimated coefficient [SE] *p-value*
279 observations

Specification:	Medium-term 3-5 year notes (a)	(b)	(c)	(d)	Long-term Bonds (a)	(b)	(c)	(d)
Constant	-0.011	-0.012	-0.011	-0.009	-0.007	-0.007	-0.007	-0.006
	[0.009]	[0.009]	[0.009]	[0.010]	[0.005]	[0.005]	[0.005]	[0.005]
	0.24	*0.19*	*0.239*	*0.33*	*0.15*	*0.12*	*0.15*	*0.20*
Nonborrowed	-0.419		-0.433	-0.411	-0.124		-0.126	-0.121
Reserves	[0.131]		[0.132]	[0.133]	[0.065]		[0.066]	[0.066]
	0.00		*0.00*	*0.00*	*0.06*		*0.06*	*0.07*
Free		-0.108				-0.024		
Reserves		[0.036]				[0.018]		
		0.00				*0.17*		
Required			0.130				0.019	
Reserves			[0.108]				[0.054]	
			0.23				*0.73*	
Gold				-0.504				-0.184
				[1.111]				[0.554]
				0.65				*0.74*
Time/1,000	0.134	0.131	0.125	0.133	0.092	0.093	0.091	0.091
	[0.152]	[0.152]	[0.152]	[0.152]	[0.075]	[0.076]	[0.076]	[0.076]
	0.38	*0.39*	*0.83*	*0.38*	*0.22*	*0.22*	*0.23*	*0.23*
Time squared	-0.005	-0.004	-0.004	-0.005	-0.004	-0.004	-0.003	-0.003
/10,000	[0.005]	[0.005]	[0.005]	[0.005]	[0.003]	[0.003]	[0.003]	[0.003]
	0.38	*0.41*	*0.42*	*0.39*	*0.18*	*0.18*	*0.19*	*0.19*
$\bar{R}^2$	0.029	0.025	0.031	0.022	0.021	0.004	0.021	0.007

Table 3 (cont.)

B) Excluding weeks around policy announcements**
263 observations

Estimated coefficient
[SE]
p-value

	Medium-term 3-5 year notes				Long-term bonds			
Specification:	(a)	(b)	(c)	(d)	(a)	(b)	(c)	(d)
Constant	-0.012 [0.009] *0.19*	-0.014 [0.009] *0.14*	-0.012 [0.009] *0.19*	-0.011 [0.010] *0.25*	-0.010 [0.005] *0.10*	-0.010 [0.005] *0.07*	-0.008 [0.005] *0.10*	-0.007 [0.004] *0.14*
Nonborrowed Reserves	-0.376 [0.130] *0.00*		-0.378 [0.131] *0.00*	-0.369 [0.131] *0.01*	-0.107 [0.066] *0.10*		-0.103 [0.066] *0.11*	-0.104 [0.066] *0.12*
Free reserves		-0.066 [0.037] *0.08*				-0.004 [0.019] *0.83*		
Required Reserves			0.022 [0.111] *0.84*				-0.033 [0.056] *0.56*	
Gold				-0.468 [1.108] *0.67*				-0.218 [0.560] *0.70*
Time/1000	0.150 [0.153] *0.33*	0.151 [0.155] *0.33*	0.148 [0.153] *0.33*	0.150 [0.153] *0.33*	0.117 [0.077] *0.13*	0.123 [0.078] *0.11*	0.120 [0.078] *0.12*	0.117 [0.077] *0.13*
Time squared /10,000	-0.005 [0.005] *0.37*	-0.005 [0.005] *0.38*	-0.005 [0.005] *0.38*	- 0.005 [0.005] *0.38*	-0.004 [0.003] *0.12*	-0.004 [0.003] *0.10*	-0.004 [0.003] *0.11*	-0.004 [0.003] *0.12*
$\bar{R}^2$	0.025	0.006	0.021	0.022	0.009	0.004	0.007	0.006

* Week of April 21, 1934 through week of August 19, 1939.
** Weeks containing these dates, and following weeks: July 15, 1936 (reserve requirements to be hiked), December 21,1936 (gold to be sterilized), January 30, 1937 (reserve requirements to be hiked), April 5, 1937 (open market operations to increase reserve supply), September 13, 1937 (partial desterilization), February 14, 1938 (more desterilization), April 14 and 22, 1938 (complete desterilization, reserve requirements to be cut, Treasury balances).

Source: Federal Reserve Board 1943, Tables 103, 123, 129. Nonborrowed reserves is "member bank reserve balances" *minus* "bills discounted." Required reserves is "member bank reserve balances" *minus* "excess."

Table 4

Weekly changes in Treasury yields, reserves and supply factors
April 1934-July 1936*

$\Delta\hat{r} = Ln\,(\Delta G + \Delta TB + R_{-1}) - r_{-1}$ Change in log nonborrowed reserves resulting from net gold flow, calculated from R_{-1} (nonborrowed reserves in prevous week) and ΔG (change in value of U.S. gold stock) and ΔTB (change in Treasury balances)

Other variables as defined in Table 3

Specifications: a) $\Delta i = Constant + \beta_T\, Time + \beta_{T2}\, Time^2 + \beta_{\hat{r}}\, \Delta\hat{r} + \varepsilon$

b) $\Delta i = Constant + \beta_T\, Time + \beta_{T2}\, Time^2 + \beta_r\, \Delta r + \varepsilon$

c) $\Delta i = Constant + \beta_T\, Time + \beta_{T2}\, Time^2 + \beta_r\, \Delta r + \beta_{rr}\, \Delta rr + \varepsilon$

d) $\Delta i = Constant + \beta_T\, Time + \beta_{T2}\, Time^2 + \beta_r\, \Delta r + \beta_g\, \Delta g + \varepsilon$

Table 4 (cont.)

117 observations — Estimated coefficient [SE] *p-value*

Specification:	Medium-term 3-5 year notes (a)	(b)	(c)	(d)	Long-term bonds (a)	(b)	(c)	(d)
Constant	-0.010	-0.004	-0.006	-0.006	-0.000	-0.006	-0.006	-0.006
	[0.017]	[0.018]	[0.017]	[0.017]	[0.007]	[0.007]	[0.007]	[0.007]
	0.71	*0.81*	*0.74*	*0.72*	*0.41*	*0.74*	*0.43*	*0.41*
Nonborrowed Reserves	-0.455	-0.391	-0.424		-0.108	-0.101	-0.101	
	[0.179]	[0.196]	[0.180]		[0.074]	[0.081]	[0.075]	
	0.01	*0.05*	*0.02*		*0.15*	*0.22*	*0.18*	
Required Reserves		-0.874				-0.096		
		[1.075]				[0.445]		
		0.42				*0.83*		
Gold			-2.475				-0.526	
			[2.043]				[0.848]	
			0.23				*0.54*	
Effect of gold and Treasury Balances				-0.483				-0.087
				[0.189]				[0.078]
				0.01				*0.27*
Time/1000	-0.130	-0.127	0.103	-0.132	0.094	0.094	0.143	0.094
	[0.678]	[0.679]	[0.703]	[0.677]	[0.280]	[0.281]	[0.292]	[0.281]
	0.84	*0.85*	*0.88*	*0.85*	*0.74*	*0.74*	*0.63*	*0.74*
Time squared /10,000	0.019	0.019	0.002	0.021	-0.007	-0.007	-0.010	-0.006
	[0.056]	[0.056]	[0.057]	[0.056]	[0.023]	[0.023]	[0.024]	[0.023]
	0.73	*0.74*	*0.97*	*0.71*	*0.78*	*0.78*	*0.67*	*0.79*
$\bar{R}^2$	0.034	0.031	0.038	0.034	-0.006	-0.015	-0.012	-0.014

* Week of April 21, 1934 through week of July 11, 1936.

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