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The Optimal Conduct of Monetary Policy with Interest on Reserves†

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In a world with interest on reserves, the central bank has two distinct tools that it can use to raise the short-term policy rate: it can either increase the interest it pays on reserve balances, or it can reduce the quantity of reserves in the system. We argue that by using both of these tools together, and by broadening the scope of reserve requirements, the central bank can simultaneously pursue two objectives: it can manage the inflation-output tradeoff using a Taylor-type rule, and it can regulate the externalities created by socially excessive short-term debt issuance on the part of financial intermediaries. (*JEL* E43, E52, E58, G21)

In October of 2008, the US Federal Reserve announced that it would begin to pay interest on depository institutions' required and excess reserve balances, having just been authorized by Congress to do so. The Fed thereby joined a large number of other central banks that were already making use of interest on reserves (IOR) prior to the onset of the global financial crisis. Given the Fed's current policy of keeping the federal funds rate near zero, IOR has not been a quantitatively important tool thus far. As of this writing, the rate being paid is only 25 basis points. However, IOR may turn out to be extremely useful going forward, given the expansion of the Fed's balance sheet as a result of its quantitative easing policies.

To see why, consider the following decomposition for the nominal federal funds rate, denoted by i:

$$i = r_{IOR} + y_{SVR}, \tag{1}$$

where r_{IOR} is the level of interest on reserves, and the y_{SVR} is the scarcity value of reserves— i.e., the convenience yield that accrues to the marginal holder of reserves.

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This decomposition implies that there are two ways for the Fed to start raising the funds rate once it decides that economic conditions warrant such an increase. It can increase r_{IOR}; or it can drain reserves from the system to the point that they become scarce again, so that y_{SVR} rises above zero.

The latter approach is only viable to the extent that the Fed is willing to greatly reduce the size of its balance sheet. As of May 2011, total reserves were nearly \$1.6 trillion; this compares to a pre-crisis value (in mid-2007) of approximately \$40 billion. Thus, to make reserves sufficiently scarce that y_{SVR} once again becomes meaningfully positive would likely imply draining over \$1.5 trillion of reserves from the system. Absent other forms of nonreserve financing (such as repurchase agreements), this would require the Fed to make a commensurate reduction in its holdings of assets such as mortgage-backed securities and long-term Treasury bonds—in other words, to unwind much of its policy of quantitative easing.

By contrast, simple arbitrage logic suggests that no matter how large the quantity of reserves in the system, the funds rate should be bounded below by r_{IOR}—for if it were not, a bank could make a riskless profit by borrowing in the federal funds market at i and depositing the reserves at the Fed to earn r_{IOR}.[1] Thus, the ability to pay IOR should allow the Fed to decouple its funds rate policy from the management of its asset holdings. For this reason, it seems likely that IOR will play an important role in monetary policy over the next few years.

In this paper, we take up a longer run question about the use of IOR as a policy tool. In its April 2011 deliberations, the Federal Open Market Committee "agreed that the size of the SOMA's [System Open Market Account] securities portfolio would be reduced over the intermediate term to a level consistent with the implementation of monetary policy through the management of the federal funds rate rather than through variation in the size or composition of the Federal Reserve's balance sheet." At this point, once it no longer needs to finance a vastly expanded balance sheet, the Fed will once again have a choice as to how to manipulate the funds rate—whether, at the margin, it should do so by altering r_{IOR} or by varying the quantity of reserves in the system so as to induce movements in y_{SVR}. Given this choice, what is the optimal way to proceed? When the Fed seeks to tighten monetary policy, should it raise the rate paid on reserves, contract the quantity of reserves, or some combination of the two?

This question can be further motivated by observing the diversity of central bank practices before the financial crisis. At one extreme of the spectrum was the Federal Reserve, which set r_{IOR} to zero, so that any variation in the funds rate had to come from quantity-mediated changes in y_{SVR}. At the other extreme was the Reserve Bank of New Zealand, which in July 2006 adopted a "floor system" in which reserves were made sufficiently plentiful as to drive y_{SVR} to zero, meaning that the policy rate was equal to r_{IOR}. And in between were a number of central banks (e.g., the ECB and the central banks of England, Canada, and Australia) which used variants of a

[1] In practice, there have been small deviations from this arbitrage relationship, with the funds rate often settling below r_{IOR}. This appears to reflect two complications. First, some holders of reserves, notably the government-sponsored enterprises, are not eligible to receive interest on reserves. And second, the arbitrage that involves banks borrowing large quantities of reserves and holding them on their balance sheets requires them to inflate their measured leverage ratios, which they may be reluctant to do because of either regulatory or market-signaling considerations. We abstract from these issues in what follows, but see Bech and Klee (2010) for a detailed treatment.

"corridor" or "symmetric channel" system. One approach to operating such a system is for the quantity of reserves to be adjusted so as to keep y_{SVR} at a constant positive level (100 basis points being a common value), with r_{IOR} then being used to make up the rest of the policy rate.[2]

Note that these corridor systems share a key feature with the floor system used by New Zealand. In either case, all *marginal variation* in the policy rate comes from variation in r_{IOR}, with no need for changes in quantity of reserves. In this sense, the pre-crisis US approach was fundamentally different from that in many other advanced economies. So it is natural to ask whether this approach can be thought of as an optimal one, and if so, under what circumstances.

A handful of other recent papers have addressed the same question that we do here. The general consensus in this literature appears to be a preference for the New Zealand-style floor approach in which the banking system is satiated with reserves at all times, and in which the policy rate is controlled entirely by the level of IOR. The basic logic—as articulated by Goodfriend (2002); Keister, Martin, and McAndrews (2008); and Curdia and Woodford (2011)—is an application of the so-called "Friedman rule" (Friedman 1959, 1969): to the extent that central-bank reserves are a valuable transactions medium, they should be made available in elastic supply and not taxed. This corresponds to the case in which $i = r_{IOR}$, and in which $y_{SVR} = 0$, i.e., where reserves are so plentiful that there is no opportunity cost to holding them.[3]

Our perspective here is quite different. We argue that, in general, it will be optimal for the central bank to take advantage of both tools at its disposal by varying both r_{IOR} and y_{SVR}, with the mix depending on conditions in the real economy and in financial markets. The two-tools argument begins with the premise that monetary policy may have an important financial stability role in addition to its familiar role in managing the inflation versus output tradeoff. In New Keynesian models, where the central bank's only job is to minimize deviations of inflation and output from desired targets, it has just one interest rate dial to turn—a dial which it is usually assumed to adjust by following a version of the "Taylor rule" (Taylor 1993, 1999).[4] However, some recent research has argued that not only should central banks also be mindful of financial stability, but that *monetary policy per se* should be a key weapon in the financial stability arsenal, above and beyond any forms of prudential regulation, such as bank capital requirements. For example, Adrian and Shin (2008) suggest that tight monetary policy should be used to head off credit booms that involve dangerous growth of intermediary balance sheets.[5]

[2] See Keister, Martin, and McAndrews (2008), and Friedman and Kuttner (2011) for a more detailed discussion of central-bank operating practices.

[3] Curdia and Woodford (2011) write: "…an increase in reserves is unambiguously desirable, in any period in which they remain below the satiation level." They then go on to say: "There are possible arguments (relating to considerations not reflected in our simple model) according to which the optimal spread might be larger than zero, but it is likely in any event to be desirable to maintain a small constant spread, rather than treating the question of the interest rate paid on reserves as a separate discretionary policy decision…"

[4] See, e.g., Gali and Gertler (2007) for a survey. Interestingly, in most New Keynesian models, the central bank is implicitly assumed to follow a New Zealand-style floor system in setting rates—that is, it simply picks the level of the nominal interest rate, with no reference to quantities of reserves.

[5] Adrian and Shin (2008) state: "In conducting monetary policy, the potential for financial sector distress should be explicitly taken into account in a forward-looking manner."

If one accepts Adrian and Shin's (2008) prescription, the appeal of a second monetary policy instrument becomes apparent: it would be difficult to manage both the inflation-output tradeoff, and financial stability, with just a single instrument. While this logic opens the door to considering a two-instrument regime in which both r_{IOR} and y_{SVR} are actively used, it does not by itself make the case. Assuming that the nominal funds rate i is still used to address the inflation-output tradeoff (as in a Taylor rule), one needs to go further and explain why variation in y_{SVR}, holding fixed i, is an effective method for achieving specific financial stability goals.

Stein (forthcoming) develops the logic for using y_{SVR} to pursue financial-stability objectives. His model has three key features. First, the central bank is purely a financial regulator. It does not need to worry about the price level, which in that model is pinned down by fiscal considerations.[6] Second, and relatedly, the central bank does not pay IOR, so it only has one tool, the nominal funds rate, which is thus equivalent to y_{SVR}. And finally, there is an externality in the capital-structure choices made by financial intermediaries. They have a tendency to take on too much short-term debt, because they do not fully internalize the social costs that short-term financing can create in an adverse state of the world.

In this setting, if reserve requirements are applied to intermediaries' short-term liabilities, changes in the quantity of reserves (and hence in y_{SVR}) can be used to implement a socially efficient, time-varying regime of Pigouvian taxes.[7] In effect, the Friedman-rule logic is turned on its head. A "reserves tax" is seen not as distortionary, but as a way of internalizing an otherwise harmful externality, and changes in the reserves tax over time represent optimal fine-tuning of this regulatory mechanism.

In what follows, we use a simplified adaptation of Stein's (forthcoming) model to illustrate how monetary policy might work in an alternative, potentially more realistic environment, where the fiscal theory of the price level is not operative. In this environment, in addition to a regulatory objective, the central bank also has responsibility for price stability, i.e., for managing the inflation-output trade-off. We do not model this latter objective explicitly, but rather just assume that the central bank pursues it by targeting the funds rate i, as in a Taylor rule. Then, given the assumption of nonzero IOR, we explore how the central bank can independently vary y_{SVR} in order to achieve its regulatory goals.

We begin in Section I by deriving the optimal regime of Pigouvian taxes levied on short-term debt claims issued by financial intermediaries. In Section II, we show how this optimal tax regime can be implemented with a system of reserve requirements, coupled with time variation in the quantity of reserves, and hence in y_{SVR}.

[6] On the fiscal theory of the price level, see Leeper (1991), Sims (1994), Woodford (1995), and Cochrane (1999). An alternative interpretation of Stein's (forthcoming) model is that the price level is fixed by a commodity standard.

[7] Other authors have also pointed out that Pigouvian taxes on the debt issued by financial intermediaries might be helpful in curbing systemic externalities (Jeanne and Korinek 2011; Kocherlakota 2010; Perotti and Suarez 2011). What is distinctive in Stein (forthcoming) is an emphasis on the fact that optimal Pigouvian taxes are likely to be time-varying, and to depend on information that is not available to the regulator. In order to elicit this information, it helps to have a market price, as in a cap-and-trade system. Monetary policy is one way of implementing such a cap-and-trade system.

In Section III, we discuss a number of practical issues that arise when monetary policy takes on a financial regulatory orientation. For example, a key implication of our analysis is that for the regulatory dimension of monetary policy to be fully effective, reserve requirements would have to be substantially broadened in their application—i.e., they should cover essentially all forms of short-term debt issued by financial firms. Thus, simply moving around y_{SVR}, without altering the scope of reserve requirements, is unlikely to yield a satisfactory outcome on the regulatory dimension. Section IV concludes.

Before proceeding, we should underscore that our analysis of monetary policy in what follows is entirely normative, as opposed to positive. That is, we offer a framework for thinking about how monetary policy might optimally be conducted when the central bank can pay interest on reserves, and when reserve requirements are structured in an appropriate way. We do not intend to suggest that our model describes how most central banks currently behave.

I. A Simple Model of Pigouvian Taxes on Short-Term Bank Debt

The model that we develop here is extremely reduced-form and partial-equilibrium in nature; see Stein (forthcoming) for a version with more explicit microfoundations. It is also close in spirit to Perotti and Suarez (2011). There is a continuum of intermediaries with total mass normalized to one, who engage in maturity-transformation activities, i.e., who make long-term loans financed with short-term debt. We refer to these intermediaries as "banks" in what follows, but it is important to recognize that they need not be traditional commercial banks. The activity that we model could equally well take place in the shadow-banking sector.

There are three dates: 0, 1, and 2. At time 0, each bank is endowed with a fixed amount of initial assets, which it simply owns, without having to finance. These assets can be thought of as comprising its capital base. In addition to a liquidating time-2 payout, these assets also yield an interim dividend at time 1. The time-1 dividend is uniformly distributed on the interval $[0, K]$.

Given its existing capital base, a bank's only choice at time 0 is how aggressively to engage in new maturity-transformation activities. In particular, it chooses a variable amount of investment I in illiquid assets. If held until time 2, these assets yield an expected payoff of θI. Banks finance a fixed fraction m of any new investment with short-maturity debt that is due at time 1, and the remaining $(1 - m)$ with long-term debt. Short-term debt is cheaper than long-term debt. The gross two-period real interest rate on long-term debt is R, while the expected cost associated with rolling over short-term financing is $(R - \Delta)$. Thus, the payoff to doing maturity transformation at scale I is given by $I(\theta - R + m\Delta)$. Clearly, maturity transformation is more attractive when banks have better investment opportunities (θ is higher) or when the spread between short- and long-term financing costs is bigger (Δ is higher).

In a more complete model, the parameters θ, Δ, and m would all be endogenously determined. For example, in Stein (forthcoming), the spread Δ, which reflects a particular violation of the Modigliani-Miller (1958) theorem, arises from the "money-like" properties of short-term bank debt—the fact that some amount of short-term debt can be made riskless, and that investors place an extra value on riskless claims because they make a particularly good transactions medium (see also Gorton 2010 and Gorton and Metrick forthcoming).[8] And the parameter m is pinned down as the upper bound on the amount of safe short-term debt that a bank can issue for a given amount of "collateral" I. Finally, a natural feature of a competitive equilibrium is that the rate of return on the marginal project θ will satisfy $(R - m\Delta) < \theta \leq R$.[9] This suggests that banks will only ever engage in maturity transformation if the spread Δ is strictly positive.

While maturity transformation allows banks to capture the spread Δ, it also has a downside. With probability p, the economy falls into a bad state at time 1, such that the long-term solvency of the banks is called into question. If the bad state hits, a bank becomes distressed at time 1 if it cannot service its short-term debt from the dividends on its preexisting assets. The idea is that when solvency is threatened, debt overhang (as in Myers 1977) makes it impossible for a bank to raise new funds at time 1, so it faces a liquidity crisis if it has a cash shortage relative to its current obligations. Thus, conditional on the bad state, and given the uniform distribution of time-1 dividends on the preexisting assets, the probability that a bank experiences distress is given by mI/K, which is a proxy for its ratio of short-term debt to capital. Simply put, doing a lot of maturity transformation increases the risk that a bank falls into distress if the economy hits the bad state.

Our key systemic risk assumption is that for any bank, the deadweight costs of distress are increasing in the fraction of the overall banking system that is in distress at the same time. Since the probability of distress for any one bank is a linear function of its level of I, and since there is a continuum of banks, the fraction of the banking system that is in distress in the bad state will depend on $\bar{I}$, the average level of maturity-transformation activity across all banks in the economy. Thus, a simple formulation of the systemic risk effect is to assume that for each bank, the deadweight costs of distress are given by $Z = \gamma\bar{I}$.

Pulling it all together, we have the following expression for the net expected profits Π of a representative bank:

$$\Pi = I(\theta - R + m\Delta) - \frac{pmI\gamma\bar{I}}{K}. \tag{2}$$

The source of the externality, and hence the rationale for regulation, flows from the fact that in maximizing expected profits, each bank takes $\bar{I}$ as fixed, thereby disregarding its contribution to aggregate systemic risk. This implies that each bank will continue to increase investment so long as $(\theta - R + m\Delta) > (pm\gamma\bar{I}/K)$. Given

[8] Stein (forthcoming) models investors as having linear utility over the quantity of riskless money they hold, which implies that the spread Δ is a fixed constant, independent of the quantity of money in the economy. But it is straightforward to consider the case where utility over money is concave, so that we get the more familiar conclusion that the equilibrium spread is decreasing in the quantity of money.

[9] If the rate of return on the marginal project were greater than R, other lenders could enter and make a profit without taking any maturity-transformation risk, simply by raising long-term funding at R. On the other hand, it can never be the case that the marginal return falls all the way to $(R - m\Delta)$ because, as described below, engaging in maturity transformation inevitably brings with it some deadweight distress costs.

that all banks are symmetric, it follows that, absent regulation, the equilibrium level of activity I^* for each bank is given by

$$I^* = (\theta - R + m\Delta)\frac{K}{pm\gamma}. \tag{3}$$

In contrast, the social planner's solution, which does not take $\bar{I}$ as fixed, involves a lower level of activity I^{**}, given by

$$I^{**} = (\theta - R + m\Delta)\frac{K}{2pm\gamma}. \tag{4}$$

We should again emphasize the highly reduced-form nature of our modeling approach, which simply posits deadweight costs of distress given by $Z = \gamma\bar{I}$. In Stein (forthcoming), the foundation for why maturity transformation can be socially excessive is based on a fire-sales mechanism; when any one bank is distressed, it is forced to sell its assets, which depresses the price at which other banks can sell their assets.[10] The subtlety, however, is that it is not obvious why fire sales create a divergence between private and socially optimal outcomes. The price impact of asset sales is a pecuniary externality, and pecuniary externalities by themselves need not lead to violations of the standard welfare theorems. The result in Stein (forthcoming), which can be thought of as a specific case of the inefficiency result in economies with incomplete markets (Geanakoplos and Polemarchakis 1986; Greenwald and Stiglitz 1986), hinges crucially on the presence of a binding collateral constraint. When this constraint is operative, any one bank's impact on market prices affects other banks not only by altering their budget constraints, but also by tightening their collateral constraints. The first welfare theorem effectively says that pecuniary externalities that operate solely through prices in budget constraints do not lead to inefficiencies, but when prices show up elsewhere, this conclusion no longer holds.

In any event, given the divergence between private and social interests in our model, one way to achieve the socially optimal outcome is with a system of Pigouvian taxes on short-term debt. If the tax rate on short-term debt is τ, the net profits of a representative bank become

$$\Pi = I(\theta - R + m(\Delta - \tau)) - \frac{pmI\gamma\bar{I}}{K}. \tag{5}$$

And the corresponding private-market outcome is altered to

$$I^* = (\theta - R + m(\Delta - \tau))\frac{K}{pm\gamma}. \tag{6}$$

[10] See also Diamond and Rajan (2011) and Shleifer and Vishny (2010) on the real costs of fire sales.

Thus, the optimal tax τ^{**} is just the value of τ that equates the expressions in (6) and (4):

$$\tau^{**} = \frac{(\theta - R + m\Delta)}{2m}. \tag{7}$$

The key thing to note here is that the optimal tax depends on the appeal to banks of undertaking maturity-transformation activities. When there is an increase in either banks' investment opportunities, (as measured by θ), or their financing spreads, (as measured by Δ), the optimal tax goes up. This suggests that not only will the optimal tax tend to vary over time with economic and financial market conditions, but, crucially, that it may depend on information that is not directly observable to regulators, since it seems plausible that banks may have private information about the nature of their investment opportunities. Thus, for example, a regulator who does not observe θ does not know enough to set the correct tax rate. Nor can such a regulator implement the optimum by setting a cap on the quantity of maturity transformation activity done by a bank, since from (4) it follows that the optimal quantity I^{**} depends on the same privately observed parameter.[11]

II. Monetary Policy as a Cap-and-Trade System

Stein (forthcoming) argues that these informational difficulties can be addressed with a system of cap-and-trade.[12] To see the logic, suppose that a regulator knows all the parameters of the model except the productivity of the banks' investment opportunities θ; this one parameter is privately observed by the managers of the banks.[13] Suppose further that the regulator endows banks with permits that allow them to issue short-term debt—for example, each permit might allow a bank to issue one unit of short-term debt, or equivalently, to do $1/m$ units of new investment. These permits can be freely traded among banks, and are issued in total quantity Q. Then for any trial value of $Q < mI^*$, i.e., for any trial value of Q such that banks in aggregate are held below their privately optimal

[11] The "net stable funding ratio" concept recently advocated by the Basel Committee on Banking Supervision is effectively a cap on a bank's use of short-term debt relative to longer term debt. As the above analysis suggests, a potentially big stumbling block for this approach is that it is very difficult for regulators to pick the right level of the cap. It should also be noted that our model is too primitive to independently speak to both capital requirements and the regulation of short-term debt. This is because the bank only has a single choice variable, which is effectively its ratio of short-term debt to assets. To make both tools relevant, we would have to allow for a richer capital structure, as well as introduce something that made long-term debt problematic, controlling for the level of short-term debt. For example, with a higher long-term debt burden, it might be harder for a bank to roll over a given level of short-term debt in the bad state—in other words, there might be an interaction between long-term solvency and short-term liquidity problems.

[12] See also Kashyap and Stein (2004) for a related discussion about the benefits of cap-and-trade in implementing capital regulation for banks.

[13] Aside from θ, it is natural to assume that many of the other parameters of the model (such as R or Δ) are publicly observable. Others, like the probability p of the bad state, may not be. However, so long as the regulator and the banks have the same estimate of these parameters, nothing that follows is changed.

level of I, the permits will trade for a nonzero price $P(Q)$ that reflects the shadow value of the constraint:[14]

$$(8) \qquad P(Q) = \frac{1}{m}\frac{d\Pi}{dI} = \frac{(\theta - R + m\Delta)}{m} - \frac{p\gamma Q}{mK}.$$

Thus, given the regulator's knowledge of Q, and of the other parameters of the model, he can simply read off from the market price of permits the key item of interest, namely θ. This is intuitive. The more attractive a bank's maturity-transformation activities, the more it will pay for permits that allow it to expand these activities. And once the regulator knows θ, he can adjust the quantity of permits in the system to their *optimal* level $Q^{**} = mI^{**}$. Moreover, at this optimal quantity, it is easily checked that the price of the permits equals the optimal Pigouvian tax, i.e., that $P(Q^{**}) = \tau^{**}$. In other words, the cap-and-trade system uses market prices to generate the information that enables a regulator to set the first-best level of taxes (or equivalently, to pick the first-best level of the cap on short-term debt issuance). For example, in a dynamic setting, if the price of permits suddenly spikes up, the regulator can infer that θ has gone up, and that he should therefore relax the cap by injecting more permits into the system.

Interestingly, in this simple formulation of the model, the optimal regulatory policy is *partially accommodative* with respect to shocks in either θ or Δ: when either of these variables increases, the regulator puts more permits into the system, thereby allowing banks to expand their maturity-transformation activities. However, this increase in permits is sufficiently small that their price—or equivalently, the Pigouvian tax on short-term debt—actually rises. This is evident from inspection of equations (4) and (7).

Stein (forthcoming) notes that one can implement a cap-and-trade system by: imposing reserve requirements on banks' short-term liabilities, controlling the total quantity of reserves in the financial system, and allowing these reserves to be freely traded in a federal funds market. In this case, the reserves are exactly analogous to permits, and there is a direct relationship between the scarcity value of reserves y_{SVR} and the price of permits P.

To be more precise, note that so far everything in the model has been expressed in real terms. In order to introduce nominally denominated reserves, suppose that the price level is pinned down outside the model, say by the usual factors in a New Keynesian model. For simplicity, let the price level at time 0 be normalized to unity. This means that any bank wishing to issue one unit of short-term debt (in real terms) must hold ρ dollars of nominal reserves, where ρ is the fractional reserve requirement. Hence, the *net* amount of short-term debt financing made possible by \$1 of reserves is $(1-\rho)/\rho$ dollars.[15] It follows that if the central bank creates an amount

[14] To be consistent with respect to time discounting, we need to assume that the permits are paid for at time 2, when the bank's profits are realized.

[15] As an example, suppose $\rho = 0.10$. In this case, with \$1 of reserves, a bank is allowed to raise \$10 of short-term debt. But given that it must hold the reserves as an asset, only nine of these dollars represent net financing that is available to fund new loans.

of reserves given by $\Re$, the effective quantity of permits Q available to the banking sector is given by

$$Q = \frac{(1 - \rho)\Re}{\rho}. \tag{9}$$

The mapping between the permit price P and the scarcity value of reserves y_{SVR} can be understood as follows. If a bank wants to increase its net issuance of short-term debt by 1 unit, it must hold an incremental quantity $\rho/(1-\rho)$ of reserves at time 0. Since it borrows these reserves at a nominal rate of i, but only earns r_{IOR}, it has to pay a nominal financing fee at time 2 of y_{SVR} per dollar of reserves held, or $\rho y_{SVR}/(1-\rho)$ in total. Allowing for the possibility of inflation between time 0 and time 2, and denoting the time 2 price level by π (recall that the time 0 price level is one), the real value of the financing fee is $\rho y_{SVR}/\big(\pi(1-\rho)\big)$.[16] This is equivalent to the permit price P, as it represents the real cost that a bank must pay at time 2 in order to increase its short-term debt by one unit.

Given this equivalence, we can write the optimal value of y_{SVR} as

$$y^{**}_{SVR} = \frac{(1 - \rho)\pi}{\rho}\tau^{**}, \tag{10}$$

where τ^{**} is the optimal Pigouvian tax from equation (7) above.

Example: Suppose the parameters of the model are such that the optimal tax on short-term debt is 25 basis points. If the reserve requirement ρ is 10 percent, and $\pi = 1.02$, corresponding to inflation of 2 percent, then $y^{**}_{SVR} = 2.30$ percent. So if the Taylor rule calls for the nominal funds rate i to be set at 5.0 percent, it would be optimal to have $r_{IOR} = 2.70$ percent, and do the rest of the job by making reserves sufficiently scarce. If the reserve requirement ρ is raised to 20 percent, then y^{**}_{SVR} falls to 1.02 percent.

III. Discussion

A. *Breadth of Reserve Requirements*

In the United States, reserve requirements are currently applicable only to a subset of commercial banks' short-term liabilities, namely their transactions deposits. This relatively narrow focus of reserve requirements is perfectly adequate for the purposes of conventional monetary policy. For as long as the induced demand for reserves is nonzero, the policy rate can be manipulated by adjusting the quantity of reserves in the system. Indeed, if this is the only goal, it is not really necessary to have any reserve requirements at all, given that some amount of reserves would still be demanded for, e.g., interbank payment and settlement purposes.

[16] Since the nominal funds rate is i, and one plus the real short rate is $(R - \Delta)$, it must be that $\pi = (1 + i)/(R - \Delta)$.

However, if monetary policy is to play the sort of regulatory role described above, it becomes important to expand the coverage of reserve requirements. First, within the traditional banking sector, reserve requirements should in principle apply to any form of short-term debt that is capable of creating run-like dynamics, and hence systemic fragility. This would include commercial paper, repo finance, brokered certificates of deposit, and so forth. Conceptually, the aim here is very similar to that envisioned in the "net stable funding ratio" concept recently put forward by the Basel Committee on Banking Supervision (2010)—to control the total amount of short-term bank debt *of any sort*—and so the coverage should be designed accordingly.

Going further, given that essentially the same maturity-transformation activities take place in the shadow banking sector (Gorton 2010; Gorton and Metrick forthcoming), it would also be desirable to regulate the shadow-banking sector in a symmetric fashion. This suggests imposing reserve requirements on the short-term debt issued by nonbank broker-dealer firms, as well as on other entities (special investment vehicles, conduits, and the like) that hold credit assets financed with short-term instruments, such as asset-backed commercial paper and repo. Alternatively, to the extent that many of these short-term claims are ultimately held by stable value money market funds that effectively take checkable deposits, a reserve requirement could be applied to these funds.[17]

B. Level of Reserve Requirements

The theory sketched above yields a unique optimum for the Pigouvian tax τ^{**} at any point in time. However, as equation (10) makes clear, it is possible to achieve a given value of τ with monetary policy tools in one of two ways: either by adjusting y_{SVR} or by adjusting the reserve requirement ρ. Thus, as in the example above, one can set τ to 25 basis points either with $\rho = 10$ percent and $y_{SVR} = 2.30$ percent, or with $\rho = 20$ percent, and $y_{SVR} = 1.02$ percent.

Is there any reason to prefer one combination over the other? One appeal of using higher reserve requirements—and hence lower values of y_{SVR}—is that this reduces the likelihood of the regulatory and price-stability roles of monetary policy colliding with one another. In particular, suppose that, according to a Taylor rule, the optimal funds rate i is determined to be 2.0 percent, and $\tau^{**} = 25$ basis points. With $\rho = 10$ percent, it is impossible to accomplish both objectives, since we would need $y_{SVR} = 2.30$ percent to hit the regulatory target, which obviously is incompatible with having $i = 2.0$ percent. By contrast, with $\rho = 20$ percent, we can set $y_{SVR} = 1.02$ percent, and meet both goals simultaneously.

As this discussion suggests, one can also implement the optimal time-varying Pigouvian tax on short-term debt by keeping y_{SVR} pegged at a constant value—as in a "corridor system"—and actively adjusting the reserve requirement ρ. Interestingly,

[17] There are clearly some difficult issues of measurement and implementation to be addressed here, given that maturity transformation in the shadow banking system typically takes place not under the roof of a single entity, but rather through a chain of transactions (e.g., a conduit acquires asset-backed securities and issues collateralized short-term commercial paper against these securities, a money market fund then buys the commercial paper and issues fixed value claims to its depositors). The challenge is to levy the proper tax on the entire chain of activity, while avoiding both gaps in coverage and double counting.

a number of central banks around the world use changes in reserve requirements as a key policy tool. For example, the Chinese central bank changed the level of reserve requirements six times in 2010, while moving their policy interest rate just once.[18]

India offers another intriguing case study. Since November 2004, the Reserve Bank of India has operated a corridor system of monetary policy. In the aftermath of Lehman Brothers' bankruptcy filing, the Reserve Bank cut reserve requirements from 9.0 percent to 5.0 percent in a series of four steps between October 2008 and January 2009. Moreover, during this same period, it also narrowed the width of its corridor from 300 basis points to 150 basis points. This narrowing of the corridor amounts to a reduction in the difference between the rate paid on reserves and the policy rate, i.e., to a cut in y_{SVR}. Thus, both policy changes had the effect of reducing the reserves tax at a time of severe stress in the financial system.[19]

Finally, Montoro and Moreno (2011) study the use of reserve requirements in three Latin American countries: Brazil, Colombia, and Peru. They note that central banks in these countries raised reserve requirements in the expansion phase of the most recent credit cycle, and then, like the Reserve Bank of India, cut them sharply after the bankruptcy of Lehman Brothers. They also argue that the motivation for this approach was explicitly rooted in a financial stability objective: "Reserve requirements could have two implications for financial stability. First, raising reserve requirements could prevent financial imbalances by restraining credit growth (and by extension, asset price increases) in the upswing of the business cycle. Second, lowering reserve requirements during a downturn can deploy the cushion of reserves built up during the expansion." (Montoro and Moreno 2011, 59).[20]

It is revealing that all of the above examples of activist use of reserve requirements come from emerging economies, where nonbank financial markets are far less developed than they are in the United States. These emerging economies mirror the assumptions in our model more closely, in that reserve requirements on bank liabilities allow the central bank to effectively regulate much of the maturity transformation in the economy as a whole. By contrast, as we have stressed above, making such regulation work in a more developed financial system—and in particular, one with a large shadow-banking sector—would require a substantial broadening of reserve requirements.

The suggestion that reserve requirements should be broader based, as well as potentially higher, may at first glance strike some as tantamount to a large and distortionary tax increase on the financial sector. While this would be the case if these changes to reserve requirements were made without paying interest on reserves, this no longer needs to be so in the presence of IOR. Quite the opposite. In our setting, the use of IOR allows the reserves tax to be targeted at precisely the level that minimizes distortions from a social planner's perspective. And as noted above, the absolute level of reserve requirements has no effect on the equilibrium reserves tax, since increases in ρ are exactly offset by reductions in y_{SVR}, or alternatively, by increases in r_{IOR}.

[18] See Du (2010) for a detailed discussion of the Chinese central bank's policies and procedures.

[19] See Reserve Bank of India (2011) for a recent evaluation of monetary policy practices in India.

[20] Montoro and Moreno (2011) also suggest that reserve requirements were, for these Latin American countries, a *better* tool for achieving financial stability objectives than movements in the policy rate. Raising the latter during the expansionary phase of the credit cycle might have drawn in further capital flows from abroad and put upward pressure on the exchange rate at a time when this was seen as undesirable.

C. *Regulatory Arbitrage*

Another skeptical reaction might be that a broad-based system of reserve requirements on the short-term liabilities of financial firms will naturally invite some form of regulatory arbitrage, i.e., an attempt to evade the rules by moving the borrowing to an unregulated entity. This is certainly true, in the general sense that any form of financial regulation can be expected to lead to some evasion. However, the relevant benchmark is not a world with no regulation and no evasion, but rather other, less efficient forms of regulation. Again, the net stable funding ratio concept recently put forward by the Basel Committee is an appropriate point of comparison. This rule seeks to regulate the same behavior—short-term debt issuance by financial firms—but does so by simply imposing a rigid cap on issuance, with no price-based feedback from the market. One danger with a cap of this sort is that one never gets to observe directly the shadow value of the constraint. Moreover, if the cap is set too tight, so that the shadow value of the constraint is very high, this is precisely when the incentive to evade the rules is strongest. Thus, the rigid cap approach embodied in the net stable funding ratio might be said to be particularly problematic on the evasion dimension.[21]

By contrast, it is a virtue of a cap-and-trade regime that when the price of the permits begins to move upward, the regulator can inject more permits into the system, thereby reducing their price and the accompanying incentives to skirt the rules. In this sense, the price-based mechanism has an inherent safety valve that can help to mitigate—though never eliminate—the regulatory-arbitrage problem. This benefit of a partial accommodation approach is likely to be especially pronounced during periods of credit expansion, whereas at such times a rigid, nonaccommodating cap is most prone to drive maturity-transformation activity underground.

D. *Reducing the Cost of Holding Excess Reserves*

As discussed earlier, previous authors have invoked Friedman (1959, 1969) to argue that it is undesirable to tax banks' holdings of excess reserves, since these excess reserves can be valuable for interbank payment and settlement purposes. Our approach would seem to run directly counter to this philosophy, since, as we have outlined it, the tax on reserve holdings would apply to both required and excess reserves. However, this feature of the design can be altered so as to maintain our core regulatory objective, while at the same time allowing excess reserves to remain untaxed, in the spirit of Friedman.

The key modification to our scheme is to let there be a different interest rate for required reserves (IORR) and for excess reserves (IOER).[22] The former is then set below the funds rate exactly along the lines described above, while the latter is set equal to the funds rate. This means that there is still a tax on any form of bank

[21] Indeed, one hypothesis for why the Basel Committee has been so slow to move forward with the net stable funding ratio—it is not scheduled for implementation until 2018—is that it is difficult to calibrate the right level of the ratio absent price-based feedback, and that there are large costs to getting it wrong.

[22] We are grateful to Roger Clews of the Bank of England and Jamie McAndrews of the New York Fed for pushing us to think in this direction.

funding that is regulated by being subject to reserve requirements, but there is no tax when banks choose to hold excess reserves for, say, interbank payments purposes.

The one subtlety with this variant is that the way the central bank learns θ is modified. Now, in order for the market to clear with IOER equal to the funds rate, the central bank must satiate the system with reserves. Therefore, the gap between the funds rate and IORR is no longer determined by a market-clearing condition, but rather must be set by the central bank. The problem is that, per our previous analysis, the optimal level of this gap depends on θ, which is initially private information of the banks. However, the central bank can still infer θ as follows. Suppose it picks a trial value of IORR somewhere below the funds rate. At this trial value of IORR, it observes the quantity of maturity transformation that banks elect to do, and hence the quantity of required reserves they hold. This combination of price and quantity allow it to deduce θ, and it can then iterate to set the optimal value of IORR that takes θ into account. In other words, in our first version of the scheme, the central bank sets quantities (total reserves) and learns from market prices (the gap between the funds rate and IOR); in this version it sets prices and learns from quantities (how much in required reserves banks choose to hold). Either way, having a reserves market where there are both observable prices and quantities allows for a better outcome than an unconditional cap on maturity transformation.

E. *Monetary Policy and Credit Bubbles*

In the simple model developed above, the only divergence between individual banks and the social planner is that each bank takes $\bar{I}$ as fixed, thereby creating a systemic-risk externality. While this is perhaps the most natural starting point for thinking about monetary policy from a regulatory perspective, there may be other effects at work that amplify this mechanism. In particular, one consideration that is often discussed informally is the idea that there can be credit bubbles—periods when private lenders make loans that would appear to have abnormally low expected returns. Greenwood and Hanson (2011) provide empirical support for the existence of something like credit bubbles, documenting that times of booming debt issuance by lower quality (e.g., junk-rated) firms are followed by significantly reduced expected returns on corporate debt relative to Treasuries.

One simple way of incorporating a credit-bubble effect into our model is to assume that there may be a wedge between the marginal return on investment as seen by individual banks, which we now denote by θ^B, and that perceived by the regulator, which we denote by θ^R. Thus, a credit bubble can be thought of as a period when $\theta^B > \theta^R$, i.e., when banks are excessively bullish on their investment prospects.

It is easy to see that this case works very similarly to that studied above, with the optimal Pigouvian tax being modified to[23]

$$(11) \qquad \tau^{**} = \frac{(2\theta^B - \theta^R - R + m\Delta)}{2m}.$$

[23] As before, the optimal tax is that which equates the privately optimal solution in equation (6) with the socially optimal solution in equation (4). The only difference is that the banks' and the regulator's differing subjective assessments of θ are now used in (6) and (4), respectively.

To put some further structure on the problem, we might posit that $\theta^R = \alpha + \beta\theta^B$, with $\beta < 1$. If we continue to assume that θ^B is private information of the banks, this formulation captures the intuition that: the regulator still has something to learn about fundamentals from banks; and yet when the banks are most optimistic about fundamentals, the regulator believes them to be overoptimistic. The formula for the optimal tax now becomes

$$\tau^{**} = \frac{((2 - \beta)\theta^B - \alpha - R + m\Delta)}{2m}. \tag{12}$$

As compared to equation (7), it is evident that the optimal tax now involves a higher coefficient on θ^B than in the baseline version of the model. In the monetary policy implementation, this implies a policy that is less accommodative than before in the face of incipient increases in y_{SVR}. As y_{SVR} begins to rise, the central bank now injects fewer additional reserves into the system, and allows y_{SVR} to go up further than it would have in the no-credit-bubble case.

We are certainly not the first to suggest that tight monetary policy might be used to try to rein in credit bubbles.[24] However, our model is more precise as to how that tightening can best be effectuated—with a contraction in reserves, and hence with an increase in y_{SVR}, rather than just by raising r_{IOR}. The intuition is straightforward: as can be seen in equation (12), credit bubbles amplify the divergence between the private and social values of maturity-transformation activity, and hence call for a higher corrective tax to internalize the externality. In contrast, increasing the funds rate via the IOR channel does nothing to address the externality.

F. *Crowding Out Short-Term Private Debt with Short-Term Government Debt*

As we have seen, the maturity transformation externality that gives rise to a role for regulation is ultimately driven by the spread Δ, which in turn reflects the money-like properties of short-term bank debt. Thus, an alternative way to address the externality would be to compress the spread. If one considers a model in which the monetary services enjoyed by households are a concave function of the supply of money—i.e., there is diminishing marginal utility of money—then it becomes possible for the government to act on the spread Δ. For example, since short-term Treasury bills are riskless, they can provide the same monetary services as short-term bank debt. Hence, in this setting, an increase in the supply of Treasury bills will reduce Δ.

One appeal of dealing with the externality in this fashion is that unlike regulatory approaches, it does not create incentives to evade the rules. Greenwood, Hanson, and Stein (2010) use this observation as the point of departure for a normative theory of government debt maturity. They argue that the government should choose a shorter debt maturity—and in particular, should issue more riskless T-bills—than it otherwise might, in an active effort to crowd out the short-term debt of financial intermediaries, and thereby minimize the associated fires-sale externalities.

[24] Again, see Adrian and Shin (2008) and the references therein.

At the same time, Greenwood, Hanson, and Stein (2010) point out that a strategy of tilting its issuance toward short-term debt is not without cost for the government, since with stochastic interest rates this increases the variability of future interest payments and ultimately disrupts efforts to smooth tax rates over time. This suggests that, in the overall optimum, the government should not issue so much short-term debt as to drive the spread Δ all the way to zero, leaving an important role for regulation of the sort that we have described. That is, these two broad strategies for fostering financial stability are likely to be complementary, with neither one making the other redundant.

IV. Conclusions

The introduction of interest on reserves gives the Federal Reserve a second monetary policy tool that, used properly, may prove helpful for financial stability purposes. By adjusting both IOR and the quantity of reserves in the system, the Fed can simultaneously pursue price stability, as well as an optimal regime of regulating the externalities created by short-term bank debt. Though to be clear, the latter would also require, in addition to the use of IOR, a significant expansion in the coverage of reserve requirements, as well as possibly an adjustment to their level.

Our analysis puts a new twist on an old notion in monetary economics—that independent of the level of nominal interest rates, it is important for the central bank to control the quantity of "money" created by the private financial sector. What is different is that here the operative definition of "money" is not just that it is a transactions medium, but that it is any form of short-term intermediary debt that has the potential to create systemic externalities. And the rationale for controlling it is not to target nominal GDP, as in a traditional quantity-theoretic model, but rather to help ensure financial stability.

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