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Are U.S. Reserve Requirements Still Binding?

I. Introduction

The Federal Reserve requires U.S. commercial banks and other depository institutions to hold a minimum level of reserves in proportion to certain liabilities. On occasion, the central bank has reduced reserve requirements—such as in 1990, when requirements on large time deposits were dropped, and in 1992, when requirements on transaction accounts were reduced. In addition, more and more banks since 1994 have used computer technologies that temporarily "sweep" deposits from one type of account to another, thereby reducing required reserve levels.

To provide customers with payments-related services, banks hold assets in two forms that also qualify as reserves: vault cash and balances deposited in Federal Reserve accounts. Such assets earn no interest when they meet reserve requirements, and traditionally the requirements have led banks to hold greater amounts of these nonearning assets than were optimal for business purposes. Reserve requirement reductions and deposit sweeping have allowed banks to lower such incremental costs.[1]

After the elimination of reserve requirements on nonpersonal time deposits and eurocurrency liabilities in 1990, the federal funds market experienced a significant surge in volatility. This occurrence, coupled with the growth in retail sweeps in the late 1990s, has raised concerns that the continued decline in reserve balances would again destabilize the federal

funds rate, thereby increasing the financing costs of borrowing banks and dealers. Despite the sharp drop in reserve balances, however, the effect on the overnight markets has been negligible, because at the same time banks have increased their reliance on Federal Reserve clearing balances and implemented more sophisticated information technologies (Clouse and Elmendorf 1997; Bennett and Hilton 1997). Banks "unbound" by reserve requirements are also less likely to be concerned with settlement day adjustments at the end of the maintenance period. Thus, the growing number of unbound banks may actually have helped diminish volatility in the federal funds market.

Nevertheless, retail sweep programs are an inefficient and costly way to avoid reserve regulations. The proliferation of these programs therefore underscores the need for reform. One approach, currently in place in several industrialized countries, is the use of an operating procedure without explicit reserve requirements (see Borio [1997] and Woodford [2000]). The current focus in the United States, however, is more predisposed to modifying existing practices to alleviate the need to work around reserve requirements. As part of this initiative, Congress approved a bill in April 2001 that would authorize the Fed to pay interest on Federal Reserve account balances two years after the bill's enactment.[2]

In this paper, we offer new statistical evidence indicating that reserve requirements have declined significantly in effectiveness, in the sense that they no longer appear to be as

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important a binding constraint on banks' holdings of assets that qualify as reserves. After reviewing definitions and concepts, we look at the trends indicating that banks have been successful in operating with significantly lower amounts of non-interest-bearing reserve assets. We also show that the periodic effects in the federal funds market associated with reserve requirements appear to be greatly reduced. Moreover, partly because of the growth of automated teller machines (ATMs), more banks have been able to fulfill their requirements entirely with vault cash. We present an econometric analysis showing that vault cash holdings have become linked more significantly to market interest rates, a finding consistent with the theoretical prediction that banks would tighten cash inventory management techniques in the absence of binding reserve requirements.

II. Bank Reserves: A Review

Most banks' marginal reserve requirements are 10 percent of demand and checking deposits.[3] Banks can fulfill these requirements with vault cash and with balances in their Federal Reserve accounts.[4] Neither of these asset categories, however, earns interest for the bank. A bank typically will use both of these assets to produce payments services, but otherwise the two types of assets are rather different and not close substitutes.

Vault Cash

Vault cash includes currency held within the United States by depository institutions. Banks use this currency for a wide variety of purposes, such as:

- money kept in ATMs;
- large cash deposits still being verified;
- large withdrawal orders being prepared for delivery;
- supplies of cash or coin stored by banks (or by their agents, such as armored carriers), for example, to meet customer requests;
- cash in transit between branch offices.

In short, vault cash is an important input to banking because a key function of banks is to provide cash services to customers. The bank's total vault cash is the sum of cash being processed or used in a variety of places and for a variety of purposes. Therefore, optimal inventory size is a rather complex

notion. Factors such as the geographic dispersion of bank offices, the cost of protection, and the mix of cash-related services demanded by the bank's customers are important determinants of how much vault cash a bank would need for business purposes, even in the absence of reserve requirements.

In addition to a bank's business uses for cash, the direct and opportunity costs of holding cash are also key determinants of optimal inventory size. One set of cost elements includes security and storage. A more important factor is the forgone return that a bank could have earned investing these funds in other ways, for example, at market interest rates. In principal, changes in market interest rates would imply corresponding shifts in the bank's optimal inventory size in the absence of reserve requirements.

Other factors being equal, banks with reserve requirements in excess of their business demand for vault cash might be expected to hold more vault cash than they otherwise would. From an internal cost-benefit viewpoint, such banks would require a correspondingly lower business-related return from vault cash at the margin, since it would also help to fulfill the regulatory requirement. In addition to inducing banks to hold more vault cash than they otherwise would, reserve requirements reduce the sensitivity of these inventories to market interest rates. When a bank's demand for vault cash is effectively decided by reserve requirements, rather than by inventory cost-benefit considerations, market interest rates become less directly relevant.[5]

Bank Balances in Federal Reserve Accounts

Similar logic applies to the balances that banks hold in their Federal Reserve accounts. Banks use these accounts to provide check clearing and electronic payments services, including the sending and receiving of funds over the Federal Reserve's wire transfer system for the settlement of their customers' commercial and financial transactions. Banks are required to avoid negative end-of-day balances in these accounts. Given the uncertain timing and size of customers' payments, banks tend to leave themselves a margin of error. They do this by aiming for an end-of-day balance big enough to minimize their risk of being overdrawn. To manage the levels of these balances, banks purchase or sell funds in their own names in the federal funds market.

The Federal Reserve is not allowed to pay interest on these account balances. However, in order to create a competitive parallel to banks offering correspondent services, the Fed offers "clearing balance" arrangements. Although these are

contractual rather than regulatory obligations, the clearing balances function very similarly to required reserve balances. In particular, they must be met over the same two-week calculation period. A distinctive feature of these clearing balances is that they earn credits that can be used by a bank to pay for Federal Reserve bank services.[6] The rate at which such credits accrue is tied to market interest rates. These credits have value only to the extent that the bank obtains priced services from the Fed, and this limits the amount of clearing balances to which a bank will commit. Beyond required reserve and clearing balances, other Fed account balances count as excess reserves and earn no interest or credits.

As with vault cash, the amount of balances a bank would keep in its Fed account is inversely related to market interest rates. A bank with little or no reserve balance requirement (for example, due to deposit sweeping or large vault cash holdings) would likely set up a clearing balance at the Fed. This would allow the bank to provide wire transfer capabilities to its customers and simultaneously earn credits to pay for check clearing and other Fed services. Because the service credit yield on banks' clearing balances moves in step with market interest rates, one effect of higher rates, then, would be to reduce the level of balances to cover a bank's service bill.[7] This is one reason why a bank's desired total Fed account balance may be lower when market rates are higher. In addition, bank customers' demands for checking and demand deposit balances (subject to reserve requirements) are also sensitive to interest rates, affecting required reserves by implication. Finally, banks may take additional steps to reduce non-interest-bearing excess reserve balances when market rates are higher. Conversely, if a bank's reserve balance requirements are large relative to the amount it would hold in its Fed account for business reasons, then its incentive to adjust independently to market rate changes would be limited.

A related point concerns the amount and timing of federal funds market activity by banks meeting their required reserve balances or clearing balances. Banks must meet their requirements with the average of end-of-day balance levels during the two-week reserve-calculation period. This would occasionally put particular pressure on a bank to buy or sell funds on the settlement Wednesday at the end of the calculation period, to dispose of excess balances or to cover balance requirements. This typically causes fed funds rates to be more volatile on such settlement days. In contrast, if banks were not subject to reserve or clearing balance requirements, they would still have to pay close attention to their daily positions, but the settlement Wednesdays would have less importance. (We return to this implication later.) Finally, it is
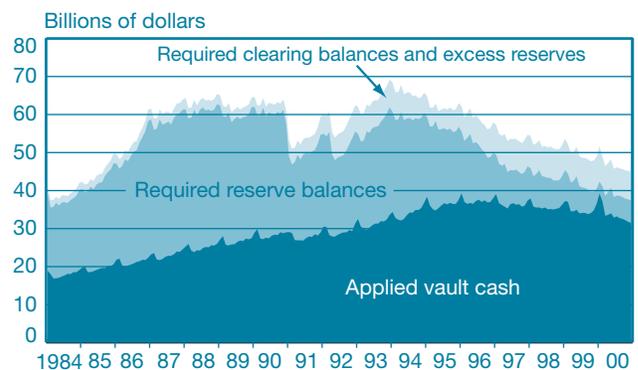
also worth noting that, if a bank keeps its Fed account balance higher than it otherwise would because of reserve requirements, such a balance would likely "turn over" less than an unconstrained account would. If reserve requirements became less binding, the turnover, or payments velocity, would rise, which we also address.

III. Trends in Vault Cash and Federal Reserve Account Balances

It is helpful to gain some perspective from aggregate trends. Chart 1 plots the composition of bank reserves and Fed account components. The bottom part of the chart represents vault cash applied against reserve requirements, which was less than half of reserves in 1990 but has become by far the largest part. Vault cash growth was spurred by the need to service public demand, particularly the demand for ATMs.

The other major reserve component in the chart, required reserve balances, has declined strikingly over the period. In 1990 and 1992, reductions in reserve requirements caused temporary declines, but the implementation of sweep accounts after 1995 had the most sustained impact on required reserve balances.[8] As Chart 2 indicates, the amount of deposits being swept through such programs has grown quite rapidly, and a gradually slowing trend is shown. We see in Chart 1 that the
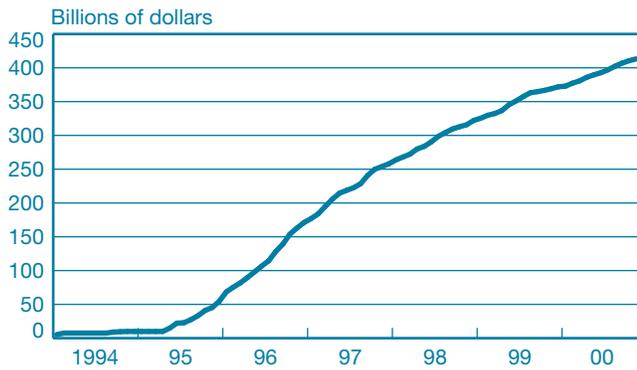
Chart 1

Components of Reserve and Account Balances at the Fed
Monthly Averages

Source: Board of Governors of the Federal Reserve System.

CHART 2

Sweeps of Retail Transaction Deposits into Savings Deposits
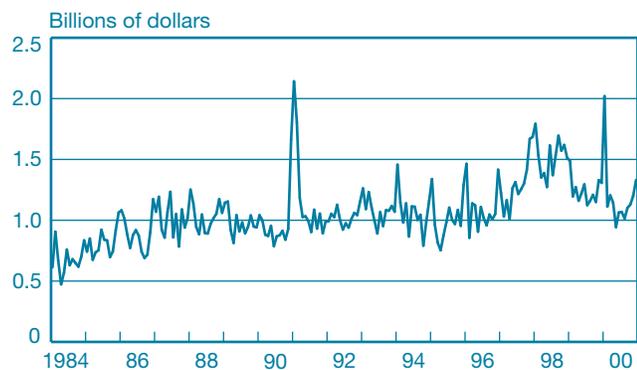
Billions of dollars

Source: Board of Governors of the Federal Reserve System.

rate of reduction in required reserve balances began to taper off after 1997, although since then, both applied vault cash and required reserve balances have continued to decline gradually. Anderson and Rasche (2001) recently developed a formal model for measuring the aggregate effect of deposit sweeps. Their study suggests that retail sweeps contributed to a $34 billion reduction in required reserves in December 1999.

Much of the reduction in reserve balances has been accompanied by an offsetting increase in clearing balances. Indeed, by mid-2000, aggregate required reserve balances had become smaller than clearing balances. This is consistent with the notion that reserve requirements were ceasing to bind, since clearing balance arrangements may fill in the difference between required reserve balances and the amounts banks

prefer for operational purposes. Through these clearing balances, which yield an implicit return, banks have been able to avoid a large build-up in zero-earning excess reserve balances (Chart 3).

The importance of sweep accounts is illustrated in Chart 4, which plots the percentages of sweeping and nonsweeping banks bound in an accounting sense (that is, banks that have a positive reserve balance requirement). With the fraction of accounting-bound sweepers falling, now only 30 percent of banks have any reserve balance requirement applicable to their Fed accounts. For the other 70 percent, vault cash now satisfies all their reserve requirements, and their Fed accounts contain clearing balances and excess reserves. For these 70 percent, reserve requirements are not effective. The requirements may not be binding for some of the other 30 percent as well. However, due to limitations on the size of a bank's clearing balances, many of the remaining 30 percent may hold required or excess reserve balances in order to meet operating needs.[9]

The fact that required reserve balances have been declining as a proportion of banks' Fed accounts is consistent with the idea that reserve requirements are ceasing to bind not only in the accounting sense but in the economic sense as well. Further support for this notion may be found in Chart 5, which plots the ratio of dollar payment volumes made through banks' Fed accounts relative to their end-of-day average balances. A shift from a low ratio to a higher ratio would be consistent with reserve requirements ceasing to bind. Thus, the chart suggests that such a shift has been well under way. The fact that the turnover ratio plotted is still rising, however, implies that the transition to a new equilibrium—with banks holding Fed account balances strictly for business purposes—is not yet complete.

CHART 3

Excess Reserves

Billions of dollars

Source: Board of Governors of the Federal Reserve System.
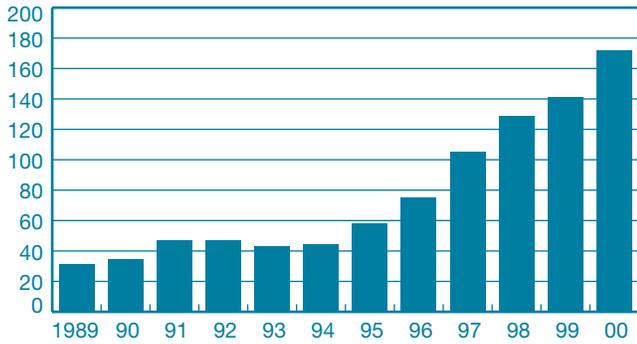
CHART 4

Proportion of Commercial Banks Bound

Percent

Source: Board of Governors of the Federal Reserve System, Report of Transaction Accounts, Other Deposits and Vault Cash (FR 2900).
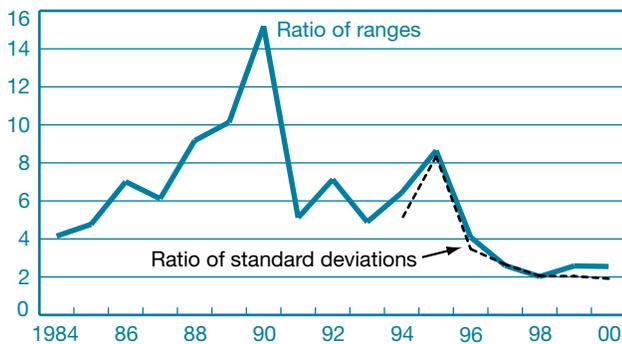
Turnover Ratio

Source: Authors' calculations, based on data from the PACS database and Board of Governors of the Federal Reserve System.

Yet another piece of evidence that reserve requirements are ceasing to bind is the recent behavior of intraday federal funds rate volatility. As noted earlier, banks trying to meet reserve and clearing balance requirements, or to shed unexpectedly large excess reserve positions, create larger volatility in the federal funds market on the last day of the reserve-calculation period. As we see in Chart 6, in recent years, the federal funds rate volatility on so-called settlement Wednesdays has diminished significantly *relative* to the average on other, nonsettlement days. The solid line in Chart 6 is based on measuring volatility as the intraday range of the federal funds

rate, while the dashed line is based on a more recently available measure: the standard deviation of intraday prices. Each measure equals the average ratio of settlement Wednesday volatility to volatility in the other business days of the corresponding two-week reserve-calculation periods.[10]

Even in the total absence of reserve requirements, some rise in volatility at the end of the calculation period could be expected, due to banks transacting to meet their (contractual) clearing balance levels (which, as noted, now exceed required reserve balances). However, if Fed account balances earned cash interest in place of the clearing balance credits, the volatility ratios would likely converge to unity. Admittedly, a number of other factors may have also contributed to lowering the intra-maintenance-period volatility of the federal funds rate. Large banks in the past few years have made great strides in improving their reserve management by installing advanced information systems for tracking payment activities. Increased consolidation among large banking organizations has also reduced uncertainty in payment flows across banks. The Federal Reserve has also made a number of adjustments to operating procedures that may have helped bring more stability to the money markets. Some of these changes include a shift to lagged reserve accounting for reserves and more frequent open market operations. Nevertheless, the rapid decline in the Wednesday volatility measures in the late 1990s is consistent with our hypothesis that reserve requirements have increasingly become less binding.

Chart 7 plots both applied vault cash (the vault cash used to meet reserve requirements, also shown in Chart 1) and total vault cash. The difference between applied and total is

Ratio of Ranges and Standard Deviations

Sources: Federal Reserve Bank of New York; Board of Governors of the Federal Reserve System.
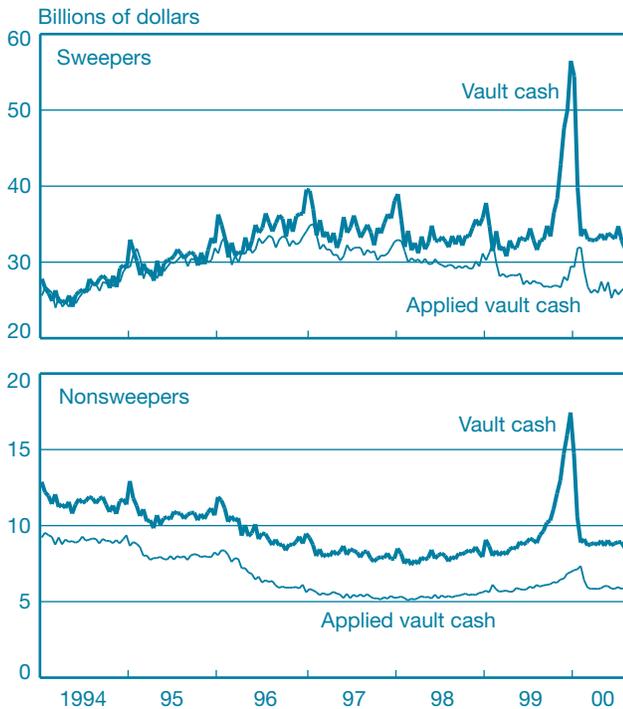
Vault Cash Levels

Source: Board of Governors of the Federal Reserve System.

sometimes referred to as "surplus" vault cash—the vault cash held in excess of individual banks' reserve requirements. The chart illustrates how total vault cash growth has slowed conspicuously, while the amount applied against reserve requirements has begun falling. It also reveals that most of the Y2K spike in vault cash was surplus, and that after January 2000, banks managed down these quantities rapidly.

The fact that surplus vault cash remains comparatively high underlines banks' increased incentives to implement inventory management methods to optimize their vault cash levels. Chart 8 divides the sample into banks that have implemented sweep accounts and others. In 1994-95, the sweepers had little or no surplus vault cash, but they have more now. Their incentive to manage this surplus therefore has grown. Incentives for nonsweepers, who have tended to have surplus vault cash all along, have changed less. Note that much more of the vault cash in absolute terms is in the hands of sweepers.[11]

In short, the ability to sweep away reserve requirements has, on balance, given banks a greater incentive to implement ways to economize on vault cash inventories. We now investigate this phenomenon more closely.

CHART 8
Vault Cash

IV. ARE BANKS MORE SENSITIVE TO THE OPPORTUNITY COST OF HOLDING CASH? EVIDENCE FROM REGRESSION ANALYSIS

We have argued that the incentives for managing vault cash have increased. These incentives, however, are not easily discernible from looking at the level of vault cash balances for sweeping and nonsweeping depository institutions. As seen in Charts 7 and 8, it is very hard to detect a significant downward trend in total cash holdings, albeit the growth in cash levels has decreased somewhat in the latter half of the 1990s. One drawback of this approach is that efforts to economize on vault cash may not actually be easy to see graphically. Similarly, it may be difficult to detect an increased sensitivity to interest rates in a chart. A more effective way to study changes in banks' vault cash management may be to use an econometric model.

In the absence of reserve requirements, the task of vault cash management by depository institutions can be viewed as a special case of the problem of optimizing the demand for money by any firm. A large literature has proposed analytical solutions to this class of operational business problems. Baumol (1952) and Tobin (1956) were the first to apply the concept of inventory modeling to cash balances. Subsequently, studies have applied such techniques in more complex versions of bank inventory optimization (see, for example, Orgler [1970]; for a more recent application of these models, see Allen [1998]). Theoretical or applied inventory models typically must start with a number of assumptions. For example, cash flows are frequently assumed to be stochastic, and the opportunity costs of holding and transferring cash balances are assumed to be positive. Even if depository institutions were not using formal optimization models, the logic in such models is sufficiently compelling for us to expect banks to be sensitive to similar variables.

We hypothesize that banks have become more focused on minimizing the costs of holding cash, whether they use sophisticated quantitative methods or rely on less formal, rule-of-thumb techniques. We have argued that since sweep accounts and reserve requirement reductions were introduced in the 1990s, bank incentives have shifted accordingly. The rapid decline in computing costs and improvements in inventory tracking may have made it more practical for banks (and other businesses) to implement such inventory management techniques. Depository institutions not bound by reserve requirements should in theory manage vault cash and Fed account balances differently than institutions with binding requirements. Without effective reserve requirements, banks should hold smaller vault cash inventories, and these should be

more sensitive to movements in market interest rates and to fluctuations in the currency needs of customers. We test this premise by constructing an empirical model of the relationship between a bank's vault cash balances and key determining variables. [12]

Definition of Regression Variables

We estimate several alternative model specifications for vault cash. Initially, we investigate the relationship between the quarterly growth of vault cash and a set of key explanatory factors. For robustness, we also estimate the regression model using as the dependent variable the ratio of vault cash to total deposits.

It is clear from our discussion in Section II that an empirical model for determining the growth or level of vault cash held by depository institutions should at least control for two key factors. First, we need to include in the regression model the opportunity costs of holding nonearning vault cash. A good measure of these costs is given by the federal funds rate, which represents the rate of return that banks can earn by lending cash assets overnight. Second, customer demand, which determines currency flows in and out of the bank, is a key factor influencing vault cash. A growing base of depositors also may increase a bank's reserve requirement and a bank's customer demand for cash services. A proxy for growth in the bank's customer base is given by growth in transaction deposits.[13]

In addition to these two fundamental determinants, vault cash balances could also be influenced by a variety of other factors. A bank's level of vault cash may exhibit certain intra-weekly patterns, falling toward the end of a week as customers make withdrawals. More appropriate for our analysis, which is done at a quarterly frequency, is the notion that vault cash may have seasonal patterns. We control for seasonal variation by including quarterly dummy variables. The inventory of currency held by depository institutions also depends on the nature and structure of the institution. The servicing needs for a small-unit (one-branch) bank are clearly much different from those of a large regional or money center bank that could have branches dispersed across many states. In our regression analysis, we attempt to control for these differences in several ways. In the most basic way, we include as explanatory variables the size and Federal Reserve District location of the bank. When appropriate, the specification includes more elaborate measures of geographic diversification.

Data

Our sample is a cross-sectional time-series panel of commercial banks between 1984 and 1999.[14] Bank-level information on vault cash and other reserve items is available from the Federal Reserve System's Report of Transaction Accounts, Other Deposits and Vault Cash (FR 2900). Table 1 presents selected summary statistics for the panel, which forms the basis of our data, combined with information from other bank databases, such as the Consolidated Report of Condition and Income for Banks and the Summary of Deposits.

In light of the huge wave of banking industry consolidation during our sample period, it is imperative that we account in our analysis for structural changes, such as mergers, as well as for failures.[15] In particular, it is critical to eliminate jumps and discontinuities associated with mergers when the dependent variable is the growth in vault cash. We use two different approaches to ensure that our final results are robust. First, we estimate the total uncombined sample of banks, using dummy regressors to control for mergers, acquisitions, or failures. Second, the regression model is estimated again for the uncombined (non-pro-forma) sample of banks, but this time we exclude all quarterly observations in which the bank participated in a merger. In addition to these two reported methods, we analyze a pro-forma version of the sample, in which merger partners were combined retroactively in the sample. The pro-forma approach is particularly useful in pre- and post-merger comparisons but less relevant in the current context. For this reason, the pro-forma analysis is not reported in the current version of this paper. Overall, however, the results are very similar.

TABLE 1
Selected Summary Statistics

Averages	1984	1990	1998
Total deposits (millions of dollars)	146	355	793
Demand deposits/total deposits (percent)	17.6	14.5	15.6
Vault cash/total deposits (percent)	1.27	0.93	0.94
Geographic dispersion	1,709	2,408	3,702
Number of banks	10,949	6,186	3,590

Source: Board of Governors of the Federal Reserve System.

Notes: Summary statistics are for all commercial banks reporting weekly in FR 2900. The geographic dispersion is measured as the total area of counties (in square miles) where a bank has an operating branch.

An added complication to our analysis was the Y2K precautionary buildup of bank vault cash (shown quite vividly in Chart 7). Rather than attempt to model this event, we conclude our sample at the end of 1998, prior to the beginning of the buildup.

Regression Findings

A simple way to investigate whether lower required reserves have influenced how banks manage vault cash is to estimate the regression model for banks that are bound in an accounting sense by reserve requirements. By definition, these banks have positive minimum reserve balance requirements to satisfy their existing Fed accounts. In contrast, an unbound bank would have no required reserve balance in its Fed account, instead holding only clearing balances or excess reserves. Accordingly, the unbound bank's opportunity cost of holding vault cash would be more closely tied to market interest rates. However, a bound bank's marginal opportunity cost of holding vault cash might very well be lower than market interest rates and relatively insensitive to market rate changes.[16] In practice, many banks switch or alternate over time between being bound and unbound by these accounting definitions.

Table 2 presents the findings for banks reporting during the 1994-98 period. The first section of the table presents the

Table 2
Factors Influencing Vault Cash Reserves, 1994-98
Dependent Variable: Quarterly Growth in Vault Cash (Percent)

Explanatory Variables	Excluding Quarter of Merger, Non-Pro-Forma			Non-Pro-Forma		
	Mostly Bound	Somewhat Bound	Unbound	Mostly Bound	Somewhat Bound	Unbound
Constant	9.175***	16.318***	15.220***	9.969***	18.748***	14.522***
	(5.37)	(6.744)	(4.50)	(5.52)	(7.76)	(4.28)
Second-quarter dummy	4.692***	3.817***	5.072***	4.128***	3.937***	5.033***
	(13.34)	(10.48)	(13.71)	(11.36)	(10.71)	(13.57)
Third-quarter dummy	2.283***	-0.030	-1.687***	1.934***	0.039	-1.715***
	(6.85)	(-0.09)	(-4.81)	(5.61)	(0.11)	(-4.87)
Fourth-quarter dummy	2.963***	-1.385***	-3.404***	2.025***	-1.421***	-3.499***
	(8.78)	(-3.95)	(-9.53)	(5.81)	(-4.04)	(-9.78)
Change in sweeps	-1.454***	-2.166***	-0.098	-1.367***	-2.181***	0.075
	(-5.42)	(-4.55)	(-0.13)	(-4.76)	(-4.61)	(0.10)
Fed funds rate	-1.020***	-1.718***	-1.792***	-1.355***	-1.796***	-1.811***
	(-4.48)	(-7.05)	(-7.61)	(5.74)	(-7.31)	(-7.67)
Demand deposit growth	0.281***	0.566***	0.634***	0.547***	0.634***	0.670***
	(24.50)	(31.68)	(28.03)	(59.37)	(49.10)	(34.61)
Number of acquisitions				3.292***	8.899***	6.238***
				(13.99)	(13.27)	(3.82)
Log of size	-0.226**	-0.359**	-0.187	-0.131	-0.546***	-0.114
	(-2.41)	(-2.03)	(-0.67)	(-1.38)	(-3.11)	(-0.41)
Adjusted R^2	0.035	0.045	0.054	0.160	0.139	0.089
Sample size	25,732	26,995	23,705	26,767	27,436	23,838

Source: Board of Governors of the Federal Reserve System.

Notes: The regression sample includes only commercial banks. Regressions also include dummy variables controlling for the Federal Reserve District location of the bank. The change in sweeps is +1 (sweep programs added), 0 (no change), -1 (sweep programs subtracted). The fed funds rate is the average rate over the previous quarter (percent). Demand deposit growth is the quarterly growth in demand deposits (percent). The number of acquisitions represents the number of takeovers in the quarter. The log of size is the logarithm of total deposits.

*** Statistically significant at the 1 percent level.
  ** Statistically significant at the 5 percent level.
   * Statistically significant at the 10 percent level.

regression analysis on the uncombined sample of banks that excludes all quarterly bank observations with a merger. In contrast, the second section reports the findings of the regression model that controls for these structural shifts in vault cash by including in the regressors the number of acquisitions. The first two columns in each section list the regression coefficients for banks that were mostly bound (bound in an accounting sense in more than half of the reserve accounting periods) and somewhat bound (bound in at least one but in less than half of the reporting periods), respectively. The third column presents the regression estimates for banks that were never bound during this period.

These regressions support the premise that the amount of cash held by banks is influenced by the opportunity cost of these assets, as reflected in the negative and significant coefficient of the federal funds rate. For every percentage point increase in the federal funds rate, our estimates suggest that vault cash for unbound institutions would decrease on average roughly 1.8 percent in a quarter. Somewhat surprisingly, in the regressions covering the entire sample period, we find that both bound and unbound banks exhibit a negative and significant coefficient on the federal funds rate. However, the regression estimates reveal that at least there is an expected ordering in the effect of federal funds. Unbound banks have the highest sensitivity to interest rates. A simple F-test confirms that the coefficients of the federal funds for unbound and mostly bound banks are statistically different at the 5 percent level of significance.

One possible explanation for the negative interest rate coefficient on the two categories of bound banks as well as on the unbound banks might be the introduction of new technologies. As sweep accounts became available in the mid-1990s, even bound banks might be motivated to manage vault cash more efficiently because they could foresee the possibility of becoming unbound in the future. In fact, the majority of institutions that introduced sweep programs after 1994 were bound. As Chart 4 illustrates, most of these banks have managed to become unbound by the end of the decade. Other banks—such as those that were already unbound—had this incentive all along. As new vault cash management methods became more available, however, such incentives would have spread even to unbound banks, pushing down their levels and inducing greater responsiveness to interest rate changes.

The significant difference in the federal funds coefficients shows that unbound banks are more proactively managing cash flows. The interest rate coefficient controls for the implicit price effects in the reduced-form equation. These findings are further reinforced by the relationship between the growth in vault cash and the growth in demand deposits. The growth in

demand deposits reflects the quantity effects by capturing shifts in vault cash resulting from variations in the bank's customer base or changes in the demand for cash. As expected, the growth in demand deposits has a significant positive effect on the growth of cash for all three categories of banks, presumably reflecting banks' response to the expanding needs of customers. Again, however, the sensitivity is strongest for unbound institutions. A 1 percent growth in demand deposits contributes to a 0.63 percent rise in vault cash for unbound banks but only a 0.28 percent rise for mostly bound banks. Unbound banks are more sensitive to the growth in demand deposits because they maintain lower excess cash holdings that must be replenished more readily to satisfy increased customer needs.

The significant negative coefficient on the change in sweeps indicates the direct role of sweep accounts in lowering currency reserves. The effect of sweeps is especially strong for bound banks, signifying the critical contribution made by this technology in decreasing vault cash balances through lower reserve requirements.

More light is shed if we separately estimate the model coefficients for subperiods. During the 1980s, banks faced fairly stringent reserve requirements and therefore were not as motivated to optimize currency reserves. During the 1990s, lower reserve requirements, the growth of vault cash in ATMs, and the availability of sweep programs encouraged banks to become progressively more proactive in their vault cash inventory management.

Table 3 presents estimates of the vault cash model for three subperiods: 1984-89, 1990-93, and 1994-98. The earlier period is identified with fairly restrictive reserve requirements. During the latter two periods, many banks were able to reduce required reserve holdings. Looking at the regression coefficients given in the table, we find again that the relationship between the growth of vault cash and its opportunity cost is negative between 1994 and 1998. In contrast, vault cash exhibits a positive and significant relationship with the federal funds rate before 1990. A positive coefficient would suggest a passive vault cash policy by banks, such as accepting larger inventories when high interest rates led customers to economize on their own cash holdings. The smaller positive coefficient on the federal funds rate in the intermediate period between 1990 and 1993 is consistent with the notion that lower effective reserve ratios may have encouraged banks to pay closer attention to limiting vault cash holdings and excess reserves.

Perhaps more revealing than the changing reaction to the implicit price of holding currency, the regression findings in Table 3 demonstrate a statistically significant shift in the quantity relationship between the growth in vault cash and the growth in demand deposits. Comparing the positive

coefficients on demand deposit growth across the three subperiods, we observe a large jump in 1994-98. This increase again suggests that cash balances during 1990-94 were more tightly linked to changing customer demands. In the earlier periods, stringent reserve requirements may have compelled banks to hold an otherwise unnecessary amount of currency passively because it would satisfy these rules. Cash on hand was more than enough to accommodate demand fluctuations and secular growth. By contrast, Table 2 illustrates that after 1994, fewer bound banks appear to manage cash reserves more

efficiently, keeping the vault cash levels more tightly managed to levels appropriate for meeting customer demands, subject to the need to respond to interest rate movements.

For robustness, we attempt a specification where the dependent variable is the ratio of vault cash to total deposits, and we obtain similar results (Table 4). In contrast to the growth rate of vault cash, this measure is noisier in that there is more unexplained cross-sectional variation in the two components of the ratio. Although this cash-to-assets ratio is a less effective measure, it does offer a simple way to examine the

TABLE 3

Factors Influencing Vault Cash Reserves across Different Periods
Dependent Variable: Quarterly Growth in Vault Cash (Percent)

Explanatory Variables	Excluding Quarter of Merger, Non-Pro-Forma			Non-Pro-Forma		
	1994-98	1984-89	1990-93	1994-98	1984-89	1990-93
Constant	12.703***	-1.634**	11.541***	13.275***	-1.104	13.116***
	(11.26)	(-2.18)	(12.75)	(11.74)	(-1.46)	(14.36)
Second-quarter dummy	4.503***	8.393***	-3.825***	4.325***	7.787***	-4.178***
	(21.47)	(53.99)	(-19.51)	(20.33)	(49.58)	(-20.91)
Third-quarter dummy	0.257	2.148***	-3.233***	0.157	1.750***	-3.472***
	(1.29)	(14.01)	(-16.48)	(0.78)	(11.28)	(-17.36)
Fourth-quarter dummy	-0.479**	4.020***	-11.884***	-0.848***	3.487***	-12.487**
	(-2.38)	(25.34)	(-59.26)	(-4.15)	(21.76)	(-61.16)
Change in sweeps	-1.726***			-1.573***		
	(-7.36)			(-6.78)		
Fed funds rate	-1.430***	0.261***	0.133***	-1.608***	0.250***	0.170***
	(-10.46)	(7.27)	(4.09)	(-11.60)	(6.87)	(5.12)
Growth in demand deposits	0.416***	0.138***	0.232***	0.609***	0.188***	0.286***
	(46.31)	(45.50)	(57.88)	(89.55)	(63.94)	(73.88)
Number of acquisitions				3.744***	11.878***	13.722***
				(17.25)	(45.21)	(43.65)
Merger/failure dummy	0.231	-0.292***	-0.714***	0.496***	-0.218**	-0.435***
	(1.41)	(-2.73)	(-5.12)	(2.98)	(-2.02)	(-3.06)
Log of size	-0.229***	-0.064	-0.312***	-0.222**	-0.084	-0.457***
	(-3.25)	(-1.18)	(-4.42)	(-3.21)	(-1.52)	(-6.44)
Adjusted R^2	0.039	0.036	0.063	0.128	0.059	0.109
Sample size	76,434	187,601	90,943	78,043	189,525	92,784

Source: Board of Governors of the Federal Reserve System.

Notes: The regression sample includes only commercial banks. Regressions also include dummy variables controlling for the Federal Reserve District location of the bank. The change in sweeps is +1 (sweep programs added), 0 (no change), -1 (sweep programs subtracted). The fed funds rate is the average rate over the previous quarter (percent). The growth in demand deposits is from the previous quarter (percent). The number of acquisitions represents the number of takeovers in the quarter. The merger/failure dummy is 1 if the bank was acquired or failed during the period. The log of size is the logarithm of total deposits.

*** Statistically significant at the 1 percent level.
** Statistically significant at the 5 percent level.
* Statistically significant at the 10 percent level.

determinants of the stock of vault cash holdings. Additional explanatory variables help control for systematic differences in the relative stock of cash held by banks. For example, banks with a greater geographic span may have to hold more currency inventories due to the high cost of moving cash inventories between offices. In Table 4, we again find strong evidence that banks are more sensitive to the economic costs of holding cash in the 1994-98 period. A 1 percent decline in the federal funds

TABLE 4
Factors Influencing Vault Cash Reserves across Different Periods
Dependent Variable: Ratio of Vault Cash to Total Deposits (Percent)

Explanatory Variables	Excluding Quarter of Merger, Non-Pro-Forma			Non-Pro-Forma		
	1994-98	1984-89	1990-93	1994-98	1984-89	1990-93
Constant	-0.150***	0.591***	-0.098***	-0.181***	0.576***	-0.114***
	(-3.63)	(34.82)	(-4.43)	(-4.52)	(34.41)	(-5.27)
Second-quarter dummy	0.028***	0.055***	0.033***	0.028***	0.054***	0.032***
	(4.17)	(16.47)	(6.65)	(4.31)	(16.45)	(6.68)
Third-quarter dummy	0.024***	0.038***	0.048***	0.026***	0.038***	0.048***
	(3.83)	(11.43)	(10.02)	(4.08)	(11.52)	(9.99)
Fourth-quarter dummy	-0.001	0.028***	-0.021***	0.005	0.029***	-0.021***
	(-0.09)	(8.34)	(-4.31)	(0.08)	(8.50)	(-4.45)
Dummy for sweeps	-0.016*			-0.022**		
	(-1.77)			(2.48)		
Fed funds rate	-0.011**	0.025***	0.003***	-0.011**	0.025***	0.003***
	(-2.21)	(32.08)	(3.78)	(-2.37)	(32.13)	(3.71)
Ratio of demand deposits	0.020***	0.018***	0.011***	0.020***	0.018***	0.011***
	(61.85)	(115.2)	(52.27)	(62.88)	(115.82)	(53.30)
Number of acquisitions				-0.005	0.027***	0.005
				(-0.84)	(5.12)	(0.91)
Merger/failure dummy	0.023***	0.055***	0.011***	0.024***	0.055***	0.011***
	(4.09)	(22.69)	(3.23)	(4.41)	(22.74)	(3.32)
Geographic dispersion	0.124***			0.123***		
	(45.81)			(46.22)		
Number of BHC subsidiaries	0.002***	-0.0001*	0.00006	0.002***	-0.0001**	0.00003
	(9.45)	(-1.79)	(0.46)	(9.48)	(-1.96)	(0.24)
Log of size	-0.025***	-0.028***	0.055***	-0.021***	-0.026***	0.056***
	(-8.82)	(-22.52)	(32.28)	(-7.78)	(-21.62)	(33.93)
Adjusted R^2	0.125	0.158	0.112	0.105	0.136	0.114
Sample size	70,761	186,069	79,109	72,399	189,525	80,776

Source: Board of Governors of the Federal Reserve System.

Notes: The regression sample includes only commercial banks. Regressions also include dummy variables controlling for the Federal Reserve District location of the bank. The dummy for sweeps is 1 if the bank initiated a sweep program, 0 otherwise. The fed funds rate is the average rate over the previous quarter (percent). The ratio of demand deposits is demand deposits divided by total deposits (percent). The number of acquisitions represents the number of takeovers in the quarter. The merger/failure dummy is 1 if the bank was acquired or failed during the period. The geographic dispersion is measured as the total area of counties (in square miles) where a bank has an operating branch. The number of bank holding company (BHC) subsidiaries represents all commercial banks operating under the same BHC umbrella. The log of size is the logarithm of total deposits.

*** Statistically significant at the 1 percent level.
 ** Statistically significant at the 5 percent level.
  * Statistically significant at the 10 percent level.

rate raises the ratio of currency to total deposits by about 1.5 basis points. Considering that this ratio does not vary much over time, such an impact of opportunity costs appears economically significant.[17] Again, the ratio of vault cash is also more responsive to demand deposits (as a percentage of total deposits) during the late 1990s compared with the earlier periods. As we have hypothesized, the Table 4 results show that the ratio of vault cash to total deposits is also influenced by geographic dispersion, measured as the logarithm of the total area of all counties where the bank has at least one branch. Banks with larger branch networks therefore appear to hold a higher share of vault cash reserves.[18]

The Influence of ATMs

An important structural factor that was left unexplored in the analysis thus far is the surge in automated teller machines. During the 1990s, the number of ATMs used by banks grew from 80,000 to 239,000 (Chart 9). ATMs account for many of the cash transactions at banks. In fact, most ATM bank networks are now connected to national or regional networks that allow easier and almost continuous access to funds.

Not only are ATMs more cost effective in dispensing cash, but they have also introduced new wrinkles to vault cash management. Today, the term "vault cash" might seem like a misnomer because a significant fraction of cash inventories may be physically located in ATMs twenty-four hours a day instead of in bank vaults. The rapid growth in ATM networks has surely altered the way in which banks manage their cash inventories. The difficulty with examining the relationship between the growth of ATMs and cash reserves is a practical

CHART 9
Growth of ATMs in the United States

Sources: *Bank Network News*; *Card Industry Directory*.

one: little or no data are collected on the amount of cash that banks hold in their ATMs.[19]
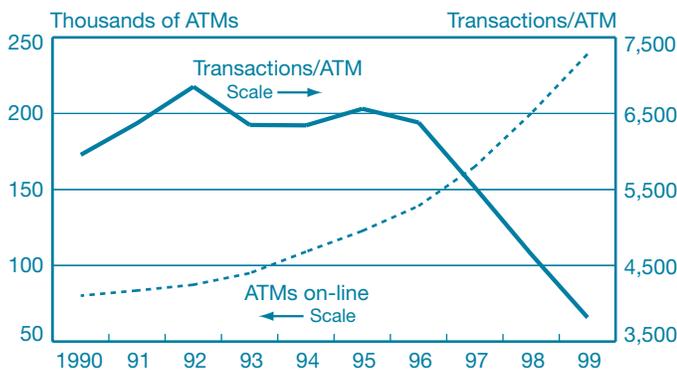
To examine the impact of ATMs, we collected data from various issues of the *Card Industry Directory*, published by Faulkner and Gray. These annual directories provide information on the 300 largest ATM owners in the United States and Canada. In addition to bank-by-bank information, the *Card Industry Directory* provides useful aggregate summaries on ATMs, such as the number of transactions per ATM shown in Chart 9. Because some of the information is summarized at the bank holding company level, we were not able to fully match all 300 institutions to our bank sample. After we eliminated all noncommercial banking institutions (mostly credit unions and thrifts) and dropped Canadian banks, the final sample consisted of an unbalanced panel of 128 commercial banks.

In addition to being an unbalanced sample, the ATM database is also more fragmented than the much larger Federal Reserve database on bank reserves. For one, banks may now drop in and out of the sample because the top 300 rankings change every year. Therefore, it is almost impossible to estimate a regression model for quarterly changes in vault cash. For the most part, the sample of ATM banks is made up of large commercial banks that initiated sweep account programs during the 1990s.

In Table 5, we look again at the relationship between the ratio of vault cash (as a percentage of total deposits) and its determinants. We find that the behavior of large ATM owners is fairly consistent with the full sample of commercial banks examined by the previous regressions. The ratio of vault cash balances is again positively related to the ratio of demand deposits, although the coefficient is very similar across the two subperiods. One minor difference is that the federal funds coefficient is now insignificant in 1994-98, although it was positive and significant in 1990-93 and it shifted in the expected direction after 1994. In a way, these findings are not surprising because the ATM sample is made up of large bound commercial banks and includes very few unbound institutions. Recall that these smaller unbound banks were mostly responsible for the negative relationship between the federal funds rate and vault cash and, more important, for the strong positive relationship between customer growth and cash holdings.

The ATM regressions again reveal that banks with sweep accounts held a lower ratio of cash balances. An important new finding, however, is that the number of ATMs is positively related to the cash ratio. Banks with more ATMs had a higher cash inventory. This result appears to support the premise that, at least initially, the rapid growth in ATMs during the 1990s has contributed in part to the rising vault cash levels. Finally, our

TABLE 5

Factors Influencing Vault Cash for Banks with Large ATM Networks (Non-Pro-Forma Comparison)
Dependent Variable: Ratio of Vault Cash to Total Deposits (Percent)

Explanatory Variables	Period		
	1994-98	1990-93	1990-98
Constant	1.661***	-0.071	1.028***
	(3.73)	(-0.17)	(3.71)
Second-quarter dummy	0.023	0.001	0.008
	(0.35)	(0.03)	(0.24)
Third-quarter dummy	0.057	0.044	0.053
	(1.01)	(1.05)	(1.56)
Fourth-quarter dummy	0.103	0.004	0.049
	(1.73)	(0.10)	(1.43)
Dummy for sweeps	-0.113**		-0.089***
	(-2.06)		(-2.60)
Fed funds rate	0.012	0.023***	0.024***
	(0.37)	(3.06)	(3.22)
Demand deposit ratio	0.022***	0.029***	0.027***
	(10.66)	(19.50)	(22.18)
Number of acquisitions	0.056	0.004	0.020
	(1.20)	(0.20)	(0.73)
Log number ATMs	0.275***	0.252***	0.267***
	(11.67)	(11.16)	(16.63)
Log of transactions/ATM	0.002	0.123***	0.043*
	(0.48)	(3.33)	(1.74)
Geographic dispersion	0.102***	0.103***	0.107***
	(5.08)	(6.61)	(8.67)
Log of size	-0.218***	-0.172***	-0.210***
	(-7.83)	(-7.05)	(-11.68)
Adjusted R^2	0.468	0.507	0.484
Sample size	712	988	1,700

Sources: Board of Governors of the Federal Reserve System; *Card Industry Directory.*

Notes: The sample is an unbalanced panel consisting of 128 commercial banks with large ATM networks. Regressions also include dummy variables controlling for the Federal Reserve District location of the bank. The dummy for sweeps is 1 if the bank initiated a sweep program, 0 otherwise. The fed funds rate is the average rate over the previous quarter (percent). The demand deposit ratio is demand deposits divided by total deposits (percent). The number of acquisitions represents the number of takeovers in the quarter. The geographic dispersion is measured as the total area of counties (in square miles) where a bank has an operating branch. The log of size is the logarithm of total deposits.

*** Statistically significant at the 1 percent level.
 ** Statistically significant at the 5 percent level.
  * Statistically significant at the 10 percent level.

findings suggest that during 1990-93, cash balances were also influenced by how extensively the ATMs were used, measured in the regression model by the log of transactions per ATM. Banks owning more extensively used ATMs were required to hold more cash reserves. This effect, however, is pretty much negligible in 1994-98, perhaps because the ATMs were used less extensively during this period.

In short, it is unsurprising that banks with wider ATM networks have more vault cash. Given the potential for specialization in such an area, one might expect certain banks to become industry leaders in efficient vault cash management techniques, with corresponding reductions in vault cash inventories for other institutions. Moreover, in the absence of the low marginal cost of holding vault cash induced by reserve requirements, the field is opened up to more competition from nonbank providers, not only for servicing but also possibly for owning the vault cash associated with the ATMs. The effective cost of providing ATM transaction services may be higher in the sense that the true opportunity cost of the cash will be market interest rates, a development that may have affected ATM transaction charges as well.

V. CONCLUSION

In this paper, we have presented evidence that reserve requirements are rapidly losing relevance. Although a sizable minority of banks are still bound by reserve requirements in an accounting sense, in an economic sense our evidence suggests that such requirements have had a lessening effect on banks for at least several years. Indeed, most reserve requirements are now fulfilled by vault cash, and by the latter part of the 1990s, banks seemed to be managing this cash more in accordance with inventory optimization methods, as opposed to complying with a quantitative regulatory minimum. It is true that the growth of clearing balance arrangements between banks and the Federal Reserve has prolonged the paradigm of the reserve holding period, but such arrangements are likely to be intrinsically limited by their links to Federal Reserve service prices, quantities, and competitiveness.

In several foreign economies, the role of reserve requirements has been reassessed or changed in recent years as the understanding of monetary policy transmission mechanisms has changed. As U.S. banks hone their abilities to manage vault cash and Federal Reserve account balances in a manner consistent with competitive returns on assets, it may be more sensible to move from quantity-based reserve requirements to more explicit, pricing-based approaches to managing these account balances.

1. Banks able to avoid holding additional nonearning assets must nonetheless bear associated reporting and other compliance costs, as well as costs of implementing and maintaining the sweep technology. In addition, there is a social cost of administration and enforcement of reserve requirements.

2. The Small Business Interest Checking Act of 2001 (H.R. 974) includes several other proposals (for a more detailed discussion, see Meyer [2001]). The bill would authorize banks to pay interest on demand deposits under the same time framework. It would also give the Federal Reserve increased flexibility in setting reserve requirements. Finally, as an interim measure for the first two years, the bill would increase the number of allowable interaccount sweeps from the current six per month to twenty-four per month.

3. In 1992, the required reserve ratio on checking accounts and business demand deposits was dropped from 12 to 10 percent, and allowances for "carrying over" balances from one accounting period to the next were liberalized. Prior to 1990, there were also reserve requirements on large time deposits and on net eurodollar funding of U.S. assets. As of December 30, 1999 (and subject to subsequent annual adjustments), reserve ratio requirements equaled only 3 percent on transaction accounts between $5 million and $44.3 million and 10 percent for any amount exceeding that range. See, for example, *Federal Reserve Bulletin*, Table 1.15 (various issues).

4. Reserve requirements are based on deposits lagged by four weeks (two computational periods). Vault cash from this computational period is applied against those requirements. If the requirement is less than the vault cash, then no reserve balance requirement exists for the bank to hold in its Federal Reserve account. Otherwise, the requirement must be met as an average account balance during the two-week reserve-calculation period. In addition, excess reserves equal to as much as 4 percent (2 percent until 1992) of a bank's reserve requirement may be "carried over" from one period to the next. However, vault cash in excess of the requirement ("surplus" vault cash) is not categorized as excess reserves and cannot be carried over to cover a subsequent period's reserve requirement.

5. Indirectly, however, banks subject to reserve requirements will be affected by how their customers react to interest rate movements. For example, a large nonbank cash user may manage cash more tightly when interest rates rise, at least temporarily pushing more cash into its bank's vault.

6. In these arrangements, the bank earns credits that may be used to pay for Fed charges for check clearing, securities transfer, or other priced services. These credits are computed based on the level of market interest rates. For more information on required reserve balances and required clearing balance arrangements, see Meulendyke (1998).

7. In addition, higher interest rates lead to a rising basis-point gap between the crediting formula and actual market rates. This also motivates the bank to economize on the amount of balances to which it will commit.

8. Typically, banks can employ one or more sweep programs at the same time. One type of sweep program moves transaction deposit balances into savings deposits over the weekend (typically at the close of Friday) and returns the funds to the transaction accounts on Monday. Alternatively, banks may sweep a portion of a depositor's transaction account balance over a predetermined threshold into a nonreservable savings account and return funds to the reservable account as needed.

9. A bank with some required reserve balances might not be affected by reserve requirements in the sense that it would have held that amount of funds anyway. The sum of such banks and the banks with surplus vault cash would equal the true total of banks not bound by reserve requirements, but only the banks with surplus vault cash can be identified using accounting data.

10. For a discussion of the effects of sweep accounts and changes in reserve requirements on federal funds rate volatility on nonsettlement days, see Bennett and Hilton (1997).

11. For further analysis of the effect of sweep accounts on reserve balances and vault cash, see Mattey and Krainer (2000).

12. There is a small literature examining vault cash management by banks. Allen (1998) uses an (S,s) inventory model to calibrate the behavior of banks. According to the theoretical inventory model, his study finds that banks have kept very high levels of reserves that cannot be justified by any reasonable variance and penalty assumptions of the model. Allen and Naples (1997) investigate a unique episode in reserve management. During a two-week period in October 1992, all vault cash holdings were ineligible to be counted toward meeting reserve requirements. As expected, banks responded by lowering cash holdings for this period.

13. Transaction deposit accounts perhaps are not the best proxy for measuring the growth in vault cash usage and the increase in the customer base. Variables such as the total number of accounts or

Endnotes (Continued)

customers might be somewhat more accurate in capturing changes in customer-driven demand for vault cash. Unfortunately, our database includes only information on the primary deposit components. We have also estimated the regression model using alternative measures of transaction accounts, such as the growth in net transaction deposits and the growth in total deposits. Overall, the regression estimates from these alternative explanatory variables were very similar.

14. The panel is "unbalanced" in the sense that not every institution is observed in every year. Our study excludes credit unions, savings and loans, savings banks, and very small commercial banks that are required to report only quarterly.

15. A list of mergers and failures was obtained from the National Information Center.

16. As noted earlier, a bank that holds required reserve balances in its Fed account—"bound" in an accounting sense—might not be bound at all in an economic sense.

17. Historically, the ratio of vault cash to total deposits has varied between 0.95 and 1.15 percent. As is evident from the regression estimates, much of the variation is explained by seasonal factors.

18. Unfortunately, we were not able to control for geographic dispersion for the two earlier periods of the regression because of data limitations. Overall, the regression estimates for 1994-98 were quite similar with or without the geographic dispersion control. As a result, we decided to include dispersion because of its strong statistical significance.

19. In addition to the cash actually in their ATMs, banks must also hold other vault cash inventories of work in process associated with ATM deposits and refills.

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