How the Bank of England Influenced British Interest Rates in the Classical Gold Standard Era

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Abstract: I use current models of monetary-policy implementation to examine the mechanism through which the Bank of England influenced, or could have influenced, British short-term interest rates in the classical gold-standard era, from the end of the 1870s to 1914. In the traditional view of this mechanism, the Bank influenced market rates for bills through reserve-supply operations and changes in Bank Rate, a published rate at which the Bank was willing to rediscount bills. I argue that the crux of the Bank's influence on money markets was actually the overnight "call money" rate. The call money rate was influenced (or potentially influenced) by reserve-supply operations but it was unaffected by Bank Rate. Bill rates were mainly determined by expected future call money rates. Bank Rate still mattered, though: it affected the bill-rate term premium - the spread between bill rates and expected future call money rates.

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There have been many studies of the Bank of England in the classical gold-standard era, that is the era from late 1870s, when several other countries linked or re-linked their currencies to gold, to the outbreak of the First World War in 1914. Modern economists have paid thorough attention to the Bank's ability to influence international gold flows and the British macroeconomy, the goals of its policymakers and its role in financial crises (e.g. Goodhart 1972; Dutton 1984; Pippenger 1984; Eichengreen 1992: 42-54; Davutyan and Parke 1995; Jeanne 1995; Flandreau and Ugolini 2013).

A relatively neglected subject is the pre-1914 Bank's system of "monetary policy implementation." This phrase refers to the mechanisms by which a central bank influences interest rates and hence spending, real activity and inflation (at least potentially, depending on the exchange-rate regime). Descriptions of the Bank's implementation system by pre-1914 contemporaries (e.g. Withers, 1910) and old economics literature (e.g. Sayers 1936) focus on the market for privately-issued bills of about three month's maturity, a key liquid asset in London money markets and an obvious channel of international arbitrage. According to many descriptions, the Bank stood ready to discount such bills or make loans on bill collateral at its published "Bank rate." Except at times of crisis, the Bank's counterparties in these transactions were not banks but rather "discount houses," independent dealers in bills that financed their inventories with overnight "call money" loans from banks. Most of the time Bank Rate was above market bill rates, hence "ineffective" with no influence on market rates. Bank Rate only became "effective" when market bill rates rose up to the level of Bank Rate. Then, Bank Rate became a ceiling on market rates. Below the ceiling, market bill rates depended on the supply of "bankers' balances," that is reserve balances held by banks in accounts at the Bank. The supply of reserve balances, part of high-powered money, was in turn affected by international gold flows and by Bank actions such as open-market operations in government securities. Gold outflows or Bank operations that drained reserve supply pushed market rates up. As banks scrambled for reserves they withdrew call money loans from discount houses and forced discount houses "into the Bank" to borrow at Bank Rate.

Remarkably, this traditional view of the pre-1914 Bank's system survives almost unchanged in the best economic literature of our own day (e.g. Dutton 1984, Ugolini 2016). Perhaps it is not surprising that the old view has largely escaped reconsideration. Policy implementation is one of the dullest aspects of central banking. Central banks have used many different systems of policy implementation depending partly on obscure features of local financial markets. All systems seem to work well most of the time.

The antique mechanism of pre-1914 London may nonetheless interest modern central bankers, as it had a feature which differed from most modern systems and which seems useful in the wake of the 2008 financial crisis. As of 2008, many central banks' systems included "standing facilities" (e.g. Federal Reserve "primary credit") that freely granted overnight credit to banks, at a rate set a bit above the central bank's target for the market overnight rate. Perhaps in homage to the pre-1914 Bank of England, such credit was sometimes referred to informally as "discount credit." It was meant to cover unpredictable shortfalls in a bank's reserve account after clearing at the end of a day or reserve-requirement maintenance period. In 2008 it proved useful in another way, as a simple form of last-resort lending, a first line of defense against runs. (In the U.S., for example, primary credit rose to enormous levels at the height of the crisis in October 2008 [Haltom 2011:6]). This desirable function of standing-facility credit was unfortunately hampered by banks' reluctance to use it. Banks feared borrowing would be taken as a signal the borrower bank was in financial distress - "stigma" (Bernanke 2009:3; Madigan 2009; Haltom, 2011; Winters 2012:60; Armantier, Ghysels, Sarkar and Shrader 2015). In response to this problem the Federal Reserve developed new tools to liquify bank balance sheets in ways that did not require an individual bank to request a loan, and ways to lend directly to nonbank securities dealers (e.g. the Primary dealer Credit Facility). For the pre-1914 Bank of England, stigma was never a problem because it provided liquidity to banks indirectly, through discount houses (Capie 2002, Gorton and Ordonez 2014, Jobst and Ugolini 2016). At least, that is the traditional view.

However, the traditional view of the Bank's system is obviously incomplete and hard to relate to current models of policy implementation. Most current models (e.g. Whitesell 2006, Ennis and Keister 2008), following Poole (1968), describe how a central bank controls market rates at the overnight maturity (e.g. fed funds and overnight repo in the U.S.), not the longer maturity of bills. In the models, the market overnight rate is determined by the interaction of reserve supply with banks' demand for reserves. The nature of reserve demand depends on particulars of the interbank payment system. The quantity of reserves demanded by banks is negatively related to the market overnight rate, as the opportunity cost of holding funds in reserves, and positively related to the costs to a bank of overdrawing its reserve account or failing to meet a required minimum balance. In pre-1914 London banks held reserve accounts in the form of bankers' balances. There was an overnight lending market in the form of call money. What determined demand for bankers' balances? What determined the market overnight rate, that is the rate for call money loans, which is largely ignored in the traditional view of the Bank's system? How was the call money rate influenced by the Bank's policy tools?

Alongside models of overnight-rate determination, another set of current models (e.g. Vayanos and Vila 2009, Greenwood and Vayanos 2014) describes how monetary authorities can influence longer-term rates, not just by affecting expected future overnight rates, but also by influencing term premiums, that is spreads between longer-term rates and expected future overnight rates. In the models, term premiums compensate risk-averse arbitrageurs who borrow and lend across maturities to profit from differentials created by other investors with preferred habitats. A central bank can influence term premiums through actions that affect the degree of day-to-day uncertainty in the value of arbitrageurs' asset portfolios, and covariances between values of assets at different maturities. Current applications of these models focus on long-term bond yields but the models apply just as well to rates on short-term liquid instruments such as bills. In pre-1914 London, how were rates for three-month bills, on which the traditional view focuses, related to call money rates? Was the term premium between bill rates and expected future call money rates influenced by Bank of England actions?

In this paper I use current models of monetary policy implementation to analyze pre-1914 London money markets and the role of the Bank of England. I argue that the traditional view is right in some ways, wrong in others. The crux of the Bank's influence on money markets was not the bill rate but rather the call money rate. The call money rate was determined by reserve supply and demand. Reserve demand reflected the process of clearing interbank payments in London by the bankes' clearing house, with final settlement through banks' reserve accounts. In choosing its bankers' balance, a bank considered the opportunity cost of holding reserve funds, which was the day's call money rate.

It traded off the call money rate against the potential cost of overdrawing its reserve account or falling short of an informal reserve requirement imposed by the Bank. The cost of a reserve-account shortfall was the cost of having to hold higher reserve balances in the future, which is to say expected future call money rates. Thus, reserve demand was negatively related to the current call money rate, positively related to expected future call money rates. The market-clearing call money rate was negatively affected by reserve supply, positively affected by expected future overnight rates, and unaffected by Bank Rate. I find evidence for this hypothesis in the observable relationship between the call money rate, the quantity of bankers' balances and Bank Rate *versus* the market rate for three-month bills. I take the last to indicate expected future call money rates.

Though Bank Rate did not affect the call money rate, Bank Rate was still an important tool for the Bank. Bank Rate affected the term premium between bill rates and expected future call money rates. That is because discount houses acted as risk-averse arbitrageurs between the call money rate and bill rates, and the terms on which the Bank provided credit to discount houses affected day-to-day variances and covariances in values of discount houses' assets. To test this hypothesis I regress the "ex post term premium," that is the spread between the three-month prime bill rate and future realized call money rates, on Bank Rate. I find that this spread was indeed positively related to Bank Rate. This was true not only when market rates were up at the Bank Rate ceiling, but also at times when market rates were far below Bank Rate and contemporaries would have judged Bank Rate to be "ineffective."

To begin, in the first section of the paper I describe the principal players in the London money market in the classical gold-standard era. In the second section I present my view and evidence on the role of discount houses as arbitrageurs between the call-money rate and bills rates, and the way the Bank influenced the bill rate term premium. In the third section I describe reserve demand, reserve supply and determination of the call money rate.

1) Overview of pre-1914 British money markets

Here I sketch of the London money market in the classical gold-standard era. Of course, many of the features I describe persisted into the interwar and even postwar eras. I focus on banks, discount houses, the Bank of England and bills of exchange.

1.1) Bills

Borrowers issued sterling bills of exchange for a variety of purposes, including among others finance of inventories or goods in transit, and purchases of long-term financial assets.[1] Maturities of newly-issued bills ranged from three months to a year. A bill of exchange could be traded on the open market once it had been "accepted" (bought) by a London bank or other financial institution: the acceptor took on liability for payment on the bill should the issuer default. The perceived quality of a bill depended on the acceptor's credit quality. Bills that had been accepted by "banks and leading firms" (U.S. National Monetary Commission 1910: 108) were called "prime" or "bank" bills. "'Other' bills" were "the acceptances of houses in a smaller position."

Prime bills were believed to be practically free of default risk (except in rare cases). They seem to have been the most liquid asset traded in London. They were widely held by foreign investors, an obvious channel of international arbitrage. International investors not only reallocated funds between London bills and foreign bills, depending on relative expected returns. They also issued sterling bills in London to finance purchases of foreign-currency assets (Margraff 1912: 34-42). It was generally believed that the balance of international investment, as a component of the British balance of payments, was sensitive to the spread between London prime bill rates and expected returns (in sterling) to holding comparable foreign-currency assets (e.g. franc bills of exchange, American commercial paper).

1.2) Discount houses

A discount house was an independent dealer in accepted bills, buying and selling them on its own account.[2] In 1910 there were about 22 discount houses; most were privately-held firms (National Monetary Commission 1910: 104). Discount houses held inventories of bills at all maturities and were considered to be "specialists in bills; they know better than anyone else the standing and means of the

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[1] "Trade bills" were drawn to finance the sale or shipment of goods and theoretically collateralized by those goods. "Finance bills" were drawn to finance purchases of financial assets, which could serve as collateral." Accommodation bills" were associated with no particular collateral or transaction (U.S. Monetary Commssion 1910: 109).

[2] When a discount house sold a bill, it became an additional guarantor of payment on the bill because it previously owned the bill (Withers 1910: 104; U.S. National Monetary Commission 1910: 107). There were other firms that served merely as brokers in bills, arranging sales between buyers and sellers, but discount houses dominated the market. Confusingly, contemporaries often referred to discount houses as bill "brokers."

parties on the bills, and they watch closely how much paper of the different firms and houses is currently on the Market" (Scott 1921: 13).

Discount houses held many types of assets in addition to bills, but all their assets were relatively liquid: British government debt at all maturities (Treasury bills, Exchequer bills [medium-term bonds], consols), local government debt, debt of the Government of India, and securities issued by private firms (bonds, perhaps equities) (U.S. Monetary Commission 1910: 107; King 1936:206; Sayers 1968: 48-51). A discount house had an account with a London bank, though which it cleared its payments. But discount houses typically left very small balances in these accounts - they held almost no "cash" (King 1936:183; Palgrave 1903:52). They held accounts at the Bank of England but kept practically no balances in them.[3]

Discount houses were funded by capital and short-term loans, mainly overnight loans, from banks, railways and "merchant houses" (Sayers 1968:52). Most overnight loans to discount houses, referred to as "call money," "day-to-day money" or "floating money," were collateralized by prime bills.[4] Some discount houses lent money at call at the same time that they were borrowing money at call themselves (U.S. National Monetary Commission 1910: 108). There was a competitive market for call money; a discount house typically borrowed from many lenders; a lender lent to many discount houses. *The Economist* reported a market rate for call money along with market rates for prime bills and other bills. Unlike bills, call money loans do not seem to have been subject to direct international arbitrage. At least, I have found no mention of such arbitrage in contemporary literature.[5]

1.3) Banks

By the end of the 1870s banks active in British money markets were mainly large "joint stock" banks. A joint-stock bank had many branches. Its head office was in London or a large "provincial"

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[3] The Bank offered two types of accounts, “deposit accounts” and “discount accounts.” Discount accounts were the type held by discount houses. They did not require an account holder to hold more than a token balance.

[4] Some of their overnight borrowing was not collateralized (Hawtrey 1938: 83). This was called "deposits" (U.S. National Monetary Commission 1910: 106).

[5] Interrnational arbitrage at the overnight maturity would mean things like borrowing at call in Paris to lend in London on the same day, or reallocating funds every morning between call lending in Paris versus London in the morning. In the later part of the gold-standard era it was possible to do this, as it was possible to buy funds in a foreign financial center for delivery on the same day through "cable exchange." But the rates charged were higher than those for "sight exchange"

city (e.g. Manchester, Birmingham). A bank head office held a reserve account (a "banker's balance") at the local branch of the Bank of England. There were bankers' clearing houses in London and other cities. A clearing house member bank paid off a net debit at the clearing house, or received a net credit, using an account held at the Bank of England. I call these "reserve accounts." Contemporaries called them "bankers' balances." A bank that was not a member of a clearing house cleared payments partly through its reserve account and partly through a correspondent account in a clearing house member bank. In a later section I will return to the details of clearing.

London joint-stock banks had practically no managed liabilities: they were funded by capital and deposits. They acted collusively, as a cartel, to set deposit interest rates. They paid no interest on checking ("current") accounts. The rates they agreed to pay for time deposits ("deposit accounts") were based on the Bank of England's announced Bank Rate: "Every time the bank rate is changed the bankers meet and fix the deposit rate...usually 1 1/2 percent under the bank rate" (U.S. National Monetary Commission 1910: 45), with "variations according to the length of time for which the depositor is prepared to fix the transaction" (Withers 1910: 31).[6] The link between Bank Rate and deposit rates is apparent in Figure 1, which plots the base deposit rate paid by London joint-stock banks on the last business day in each month along with Bank Rate on the Friday of the same week. (I take the deposit rate from Capie and Webber 1985: Table III (10). I take Bank Rate from the Neal and Weidenmier (2005) database. Both series were constructed from reports published in the *Economist*.)

Along with reserve accounts, joint-stock banks held till money, kept at a fairly stable fraction of a bank's checking-account balances (Goodhart 1972:98-99), and surprisingly large additional reserves of currency and coin.[7] After high-powered money, banks' next-most liquid, next-shortest duration asset was loans to discount houses which were usually at call and collateralized by bills (Hawtrey 1938: 83; Clare 1902:146; Goodhart 1972:122; U.S. National Monetary Commission

(which was delivered in the foreign center a few days after purchase) (Whitaker 1920: 89). I speculate that the high transactions cost of cable exchange made it unprofitable to arbitrage call-money rates across cities.

[6]Banks outside London did not link their deposit rates to Bank Rate (Withers 1910: 102).

[7] Goodhart (1972:100-101) speculates that banks held these reserves, rather than additional balances at the Bank of England, because banks did not entirely trust the Bank to provide enough coin and currency in an emergency.

1910:41, 119). Banks made a lot of loans to stock brokers on stock and bond collateral (with a 10-20 percent haircut), but most of these were for a longer term, about two weeks.[8]

Longer-term liquid assets held by banks included all those held by discount houses, including accepted bills bought on the open market. But unlike discount houses, banks did not treat bills as *liquid* assets. A contemporary observed: "In practice,..banks rarely, if ever, re-sell the bills they have bought under discount. There is no particular reason why a bank should refrain; but, as the matter stands, it seems to be considered *infra dignitatem* for a banker, once he has acquired a bill from the discount market, to offer it again for sale" (Spalding, 1930, p. 138; see also Sayers 1936: 21; King 1936:92ff).[9] Capie and Webber (1985:313) observe that "The bill was thus an irrevocable lock-up of funds" for a bank. Since bills were practically illiquid as far as banks were concerned, banks did not usually buy bills of more than three months' maturity (U.S. National Monetary Commission 1910: 71, 109). Bank staff managed the maturity structure of a bank's bill portfolio so it would throw off cash for predictable needs (Spalding 1930:138).

Finally, banks made short-term loans to customers, usually by "discounting a bill" for a customer whose bill would not trade on the open market. (Some bank managers said they based the rate charged for such loans on Bank Rate [U.S. Monetary Commission 1910: 53-54, 81], but other contemporary observers said this was not generally true [Withers 1910:31].)

1.4) The Bank of England

The Bank of England took deposits from banks, the British government, local governments, foreign governments and central banks. It also took deposits from "private customers." These were nonbank firms, even individuals that used Bank of England accounts as ordinary checking accounts. For its bank and private customers the Bank provided most of the services an ordinary British bank provided to customers and respondent banks. These included rediscounting of bills and provision of

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8 . Sales of stocks and bonds on the London exchange were settled only twice a month. Thus, to finance their inventories brokers borrowed for the span of time between settlement days (U.S. National Monetary Commission 1910: 44, 73, 119; Withers 1910: 104; Straker 1920: 53; Whitaker 1920: 214).

9 I speculate that this was because a bill accepted by a bank were carried as a liability on the bank's balance sheet (U.S. National Monetary Commission 1910: 72), but a bill bought and sold by a bank was not, even though the bank (like a

short-term loans - “advances” - on collateral of bills and/or marketable securities. The Bank did not pay interest on any type of deposit.

From the 1850s to 1878, the Bank rediscounted prime bills for its bank and private customers at Bank Rate. This was a publicly announced rate, officially the Bank's minimum rate of rediscount for high-quality bills. The Bank refused to rediscount bills for discount houses except at times of crisis, or at particular times of the year when interest rates were seasonally high.

In 1878 the Bank announced it would thenceforth rediscount bills for its customers, including banks, at market rates. It also announced that it now stood willing to make advances to discount houses on collateral of bills or securities. Initially, the term of an advance had to be at least a week, no more than two weeks, and the rate charged was Bank Rate (Palgrave 1903:51; Spalding 11930:89, Sayers 1968: 58, Sayers 1976: 35-36). At this time, therefore, "Bank Rate was not a rediscount rate at all, nor even a discount rate for customers' paper. It was the rate at which the bill market could obtain advances for a week or a fortnight" (Sayers 1936: 3).

After 1878 the rate charged for advances to discount houses did not remain equal to Bank Rate. At times between 1878 and 1903 the advances rate was set at Bank Rate *plus* 1/2% or 1%. In 1903 the Bank set the advances rate at Bank Rate *plus* 1/2% and kept to that spread through 1914 (and long after). From time to time the Bank loosened or tightened its standards for the assets it would take as collateral (Sayers 1968: 57-58).

In July 1890 the Bank began to allow discount houses to rediscount bills at Bank Rate. At first discount houses could present only very short bills, with fifteen days or less remaining to maturity. Starting in 1895 discount houses were allowed to present bills of up to 63 days, still at Bank Rate. Sometimes Bank officials communicated that they were temporarily willing to take bills of maturity greater than 63 days from discount houses (Sayers 1976: 35-36). However, rediscounting of bills did not entirely replace advances as a channel of Bank credit to discount houses. Discount houses continued to borrow from the Bank through advances (Sayers 1936: 22, 1968: 55-58). Over 1890-1914 one house went into the Bank for advances on average about twelve times a year, and rediscounted

discount house) was an additional gurantor of payment on a sold bill. Thus, selling bills would create an invisible, unfunded about three times a year (Sayers 1968:56). In 1895 total lending through advances to discount houses was about 80 percent of rediscounts (Clapham 1944:369).

All the while the Bank stood ready to rediscount bills at market rates for its private customers and banks (Mackenzie 1932:13). Private customers often took it up on the offer. Banks did *not* except at times of crisis (U.S. National Monetary Commission 1910: 21). Apparently, this was because of stigma:

> in London if it were known that a bank, even of the highest standing, habitually re-discounted with the Bank of England, it would at once be held to be 'in extremis.' In times of panic and peril such things, of course, have to be done, but in the ordinary way of business no London banker ever dreams of such a thing (Palgrave 1903: 52).

There seems to been no stigma associated with a discount house rediscounting at or borrowing from the Bank.[10] Discount houses were always willing to take funds from the Bank when it was immediately profitable to do so. Contemporaries and Bank policymakers believed that the costs of Bank advances and/or rediscounts put a ceiling on short-term market rates. Bank Rate was one determinant of those costs, but not the only one. There was also the spread between the advances rate and Bank Rate, the term of an advance and required quality of collateral, and the types of bill the Bank would take to rediscount. All of these varied over time. Thus there was no simple relation between Bank Rate and the ceiling on market rates. Long after the Bank had begun rediscounting for discount houses it was possible for the market rate on three-month high-quality bills to exceed Bank Rate (Sayers 1936: 60-65). This is apparent in Figure 2, which plots Friday values of Bank Rate and market discount rates for prime three-month bills over 1889-1910 (from the Neal and Wiedenmier [2005] database; for bills I average bid and ask rates). Figure 3 plots the reported market call money rate for

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and hard-to-estimate libility for a bank. I speculate that it therefore became good banking practice *not* to resell bills.

[10] It is not obvious why such stigma did not develop. After all, in 1866 the failure of Overend, Gurney, a firm known as a discount house, had touched off a general panic in London financial markets. Perhaps it is relevant that the firm was perceived to have failed only partly because of capital loss in its discount business; a bigger problem was bad investments in long-term, illiquid assets. As noted above, in later years discount houses held only very liquid assets. Also, Overend,Gurney was not borrowing from the Bank in the run-up to the crisis; the Bank of England had not yet adopted a policy of regular lending to discount houses (King 1936: 214-216; 242-256; Flandreau and Ugolini 2013).

the same day of the week, kindly provided by Stefano Ugolini.[11] At times, even the call money rate exceeded Bank Rate.

Bank policymakers set Bank Rate and other terms of credit to discount houses to achieve three, sometimes conflicting objectives. Their primary objective was to maintain the Bank's ability to exchange the Bank's notes and deposits for gold, at a fixed rate. Subject to this primary objective, they wanted to make profit for the Bank's shareholders. Finally, they wanted to keep the cost of credit to British businesses low and stable, though they did not have a notion of macroeconomic stabilization in the modern sense (Sayers 1976:8; 1936:117-127). Certainly, they did not aim to stabilize the price level in the way that Federal Reserve policymakers did in the 1920s (Orphanides, 2003; Meltzer, 2003: 169,209,230).

By the end of the 1870s, monetary authorities of other major countries were exchanging their own currencies for gold. This constrained rates of foreign exchange against those currencies. Costs of shipping gold between financial centers held exchange rates within bands called "gold points." It was profitable to buy gold from the Bank and ship it out of Britain when exchange rates depreciated down to the "gold export point." It was profitable to ship gold into Britain and sell it to the Bank when exchange rates appreciated up to the "gold import point." Neither the Bank nor the Treasury maintained official reserves of foreign assets. Neither bought or sold gold in foreign markets. Thus, a balance of payments deficit (surplus) was accompanied by depreciation (appreciation) of exchange rates to the lower (upper) gold point, and sales (purchases) of gold by the Bank.

Bank policymakers could not let a gold drain caused by a balance-of-payments deficit (an "external drain") go on too long, though there were several things they could do that could help for a while.[12] If the drain persisted the Bank had to raise London bill rates relative to foreign interest rates,

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[11] These are the figures reported in the *Economist* as "Loans, day to day," not "discount houses at call," which was the rate paid by discount houses for "deposits" (uncollateralized loans).

[12] They could buy or borrow gold from other central banks (e.g. Clapham 1944: 330). They could persuade foreign central banks which held reserves of British assets to buy more British assets and hence reduce Britain's balance-of-payments deficit (Clapham 1944:388). They could use "gold devices," actions that temporarily stretched the lower gold point, to allow the pound to depreciate more before gold flowed out and ameliorate the balance-of-payments deficit resulting from any given spread between London bill rates and foreign interest rates. In the classical gold-standard era there was never serious doubt that the Bank would stop paying out gold for currency or change the gold exchange rate, so the gold points defined a credible exchange-rate "target zone" (Bordo and MacDonald 2005). When the exchange rate was at the export

to tip the balance of international investment toward Britain. Policymakers believed that gold sales by the Bank, which decreased British high-powered money supply, tended to raise London bill rates automatically. But to hurry up the process and bring a quicker end to the drain Bank policymakers often took other actions to reduce the high-powered money supply. These included outright sales or reverse repos ("budlas" [Spalding 1930: 101]) of government debt. The Bank also reduced reserves by soliciting loans from London banks and discount houses (Sayers 1958:49, 1976: 37-41).[13]

Of course, these actions would have done little good unless the Bank raised the cost of Bank credit to discount houses, to lift the ceiling on market rates. The Bank could do this by raising Bank Rate. But Bank policymakers were keenly aware that London banks' cartel created a peculiar link between Bank Rate and bank deposit rates. They believed that an increase in bank deposit rates meant an increase in bank lending rates as well. Thus, an increase in Bank Rate conflicted with one of the Bank's secondary goals, that is low and stable costs of credit to businesses. Often, when Bank policymakers needed to raise market bill rates to draw in gold, they left Bank Rate alone and raised the spread between Bank Rate and the advances rate, or tightened up on the quality of bills taken for rediscount or as collateral for advances, or simply raised the rediscount rate for discount houses above Bank Rate (which was officially just the Bank's *minimum* rate of rediscount for non-customers).[14]

When there was a balance-of-payments surplus the Bank could purchase gold and build up its reserves. This was necessary if a previous drain had left reserves low.[15] But Bank policymakers' desired gold reserve was remarkably small relative to other central banks'. They never sterilized gold

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(import) point, people expected future appreciation (depreciation) of the pound roughly equal to the difference between the gold point and the long-run average value of the exchange rate between the gold points. For a given spread between London bill rates and foreign interest rates, expected future appreciation (depreciation) of the pound had a positive efefct on the balance of payments and hence gold inflow. Gold devices were actions that temporarily stretched the gold points by changing the cost of shipping gold abroad, or the forms in which the Bank would provide or purchase gold (foreign coin *versus* bullion and so on) (Sayers 1936:71).

[13] Selling off some of the Bank's portfolio of rediscounted bills would have had the same effect, but the Bank never sold or bought bills in the open market (Sayers 1936:19-20).

[14] In late September 1906 "notwithstanding the published 4 per cent Bank Rate, it charged the market [disocunt houses] 4 1/2 on discounts and 5 on advances" (Sayers 1976:55). "This latter working on Market Rate in a sense independently of Bank Rate was based on the accepted fact that while Bank Rate ruled the majority of home banking charges, Market Rate was the rate which influenced foreign exchanges. If, therefore, the Bank, in its tenderness toward the internal situation, wished to act on the foreign exchnages without forcing higher rates on home trade, it could use the devices..to force Market Rate up beyond its normal 'effective' relationship with Bank Rate" (Sayers1936:49-50).

[15] Sometimes Bank policymakers used gold devices that temporarily lowered the gold import point to spur gold imports.

inflows to let gold reserves keep building up year after year (as did the Federal Reserve and Bank of France in the 1920s). They allowed gold purchases to boost the money supply and lower market rates. This may have been partly because of their secondary objective to make a profit: the opportunity cost of holding gold reserves was the loss of potential interest earnings on financial assets. In any case, when gold was flowing in the Bank usually let market rates fall and took the opportunity to lower Bank Rate. "Its predisposition always favored a low rather than a high Bank Rate, because this official rate affected lending rates throughout internal banking business, and the Bank's policy was always to create as favourable conditions as it could for home trade, consistently with the interest rates necessitated by the international capital situation" (Sayers 1958: 49).

At the same time, Bank policymakers do not appear to have attempted to maintain a consistent, standard spread between Bank Rate and market rates, even in the fairly long run. This is apparent in Figure 2. Sometimes Bank policymakers left Bank Rate far above market rates for many months, as in the mid-1890s, late 1908 and 1909. In the short run, the spread between market rates and Bank Rate also varied because Bank policymakers adjusted Bank Rate in large, discontinuous steps, almost always at the regular Thursday meeting of the Bank's policy committee (the "Court"). When they cut Bank Rate, they usually cut it in increments of exactly one-half percent; when they raised Bank Rate, they usually raised it in increments of exactly one percent (Sayers 1936:50; 1958:61-62).

2) How the Bank influenced term premiums in bill rates

In this section I argue that the Bank could influence term premiums in bill rates with its setting of Bank Rate. First I review current models of central bank influence on term premiums. Then I relate those models to pre-1914 London money markets. I hypothesize that discount houses acted as risk-averse arbitrageurs between the call money rate and bill rates. Bill rate term premiums could be affected by the terms of Bank credit to discount houses because those terms affected day-to-day variances and covariances in values of assets in discount houses' portfolios. To test this hypothesis I regress the "ex post term premium," that is the spread between the three-month prime bill rate and future realized call money rates, on Bank Rate.

2.1) Current models of term premiums

In models with perfect financial markets and a representative household, a central bank can influence interest rates only through expectations of future overnight rates: it has no lever on term premiums, that is spreads between expected future overnight rates and bond yields (Eggertsson and Woodford, 2003). Since 2008, however, many central banks have engaged in operations intended to reduce term premiums: "quantitative easing" (QE), in which the central bank acquires long-term bonds in exchange for newly-created reserve balances or short-term Treasury debt from the central bank's portfolio. Many current interpretations of QE operations rely on the "preferred habitat" theory of Modigliani and Sutch (1966). Much current literature (e.g. Krishnamurthy and Vissing-Jorgensen, 2011; Gagnon et. al. 2011; D'Amico et. al. 2012) refers specifically to a model developed by Vayanos and Vila (2009) in which preferred-habitat investors interact with risk-averse arbitrageurs. In this model, the general level of term premiums increases with the degree of unpredictable day-to-day variance in the value of arbitrageurs' bond portfolio. The term premium at a specific maturity depends on the covariance between the value of arbitrageur's bond portfolio and values of bonds at that specific maturity. A central can affect term premiums by affecting that variance or covariance.

Following Vayanos and Vila, consider a model in which there are two types of asset: liquid zero-coupon bonds (or bills) paying off at various maturities; and very short-term loans corresponding to overnight loans, available in any quantity at an exogenously determined interest rate. The short-term rate is somewhat unpredictable so bond prices are subject to duration risk. There are two types of investor. A preferred-habitat investor demands bonds at just one maturity. His demand for bonds at that maturity depends only on exogenous factors and that asset's own interest rate or yield. An arbitrageur may hold assets in positive or negative quantities at any maturity (that is, he can issue bonds). An arbitrageur is risk-averse with "mean-variance" preferences (as in Sharpe's [1964] Capital Asset Pricing Model). In the absence of arbitrageurs, bond demands of preferred-habitat investors would create a term structure of bond yields unrelated to expected future overnight rates. As arbitrageurs borrow overnight to buy bonds, they pull bond yields toward expected future overnight rates. But because arbitrageurs are risk-averse, in equilibrium there must be term premiums to compensate them for taking on duration risk.

Following Hamilton and Wu (2014), set the model in discrete time. A period is a day. An arbitrageur, indexed by *j*, maximizes:

(1) $$E_t \Delta W_{j,t+1} - \frac{a_j}{2} Var(\Delta W_{j,t+1})$$

where W_j is the arbitrageur's wealth. Following Greenwood and Vayanos (2014), allow for a negative relationship between wealth and the risk-aversion parameter a_j. To simplify notation let $a_j = a / W_j$ specifically. The resulting objective function implies that an arbitrageur wants to avoid variance in the value of his assets net of liabilities, that is his capital, in ratio to the current value of his capital. One interpretation of this is that it approximates an objective function in which the arbitrageur must pay a cost if his capital falls below a certain fraction of the value of his assets. The probability of that event increases with the degree of variance in the value of the arbitrageur's capital (wealth), relative to today's capital value.

Given (1) and common beliefs, all arbitrageurs hold the same portfolio of risky bonds. r_t is the spread between the expected return to holding this portfolio overnight (from *t* to *t+1)* and the overnight rate i_t (expressed on a daily basis). r_{kt} is the spread between the expected overnight return to holding a particular bond *k* and r_t. Normalizing the final payoff of a zero-coupon bond to one, its log price is approximately:

(2) $$p_{kt} \approx - \ E_t \left[\sum_{\tau=0}^{d_k} \left(i + r + r_k \right)_{t+\tau} \right]$$

where d_k is the bond's duration in days. Its yield to maturity is:

(3) $$i_{kt} \approx \frac{1}{d_k / \zeta} E_t \sum_{\tau=0}^{d_k} i_{t+\tau} + \frac{1}{d_k / \zeta} E_t \sum_{\tau=0}^{d_k} \left(r + r_k \right)_{t+\tau}$$

where ζ is the number of market days in a year. The first term on the right-hand side of (3) is the expected value of the average overnight rate over the lifetime of the bond. The remaining one is the term premium. The term premium has a common component built into yields of all bonds: current and expected future *r.* It also has a maturity-specific component: current and expected future r_k.

The specific component is determined by the relationship between day-to-day variations in the value of the bond, and variations in the value of the whole bond portfolio:

$$(4) \qquad r_{kt} = (\beta_{kt} - 1)\, r_t \quad where \quad \beta_{kt} \approx \frac{\sigma_{kp,t+1}}{\sigma^2_{t+1}}$$

where σ^2_{t+1} is the perceived variance of the log of tomorrow's value of the portfolio, and $\sigma_{kp,t+1}$ is the perceived covariance of the log portfolio value with the log value of bond *k*. (β_{kt} is, exactly, the covariance of the realized overnight return to holding bond *k* with the portfolio return. The approximation holds for realistically small values of *i* and *r*.) Thus, a decrease in covariance of a bond's value with the value of arbitrageurs' entire bond portfolio reduces the term premium on that bond.

The common component *r* (the expected return to the bond portfolio less the overnight rate) is determined by the interaction of arbitrageurs' demand with demand of preferred-habitat investors and bond supply. An increase in arbitrageurs' demand for bonds at a given value of *r* tends to raise bond prices, lowering *r*. The total value of bonds arbitrageurs desire to hold is (from maximization of (1)):

$$(5) \qquad V_t = W_t \, \frac{1}{\eta_t a} \, \frac{r_t}{(1+i+r)_t^2} \quad where \quad \eta_t \approx \sigma^2_{t+1}$$

where *W* is total arbitrageurs' wealth. (η_t is, exactly, the variance of tomorrow's portfolio value divided by the square of its expected value.) (5) shows that a decrease in the perceived variance of log portfolio value tends to increase arbitrageurs' demand for bonds. Hence it tends to decrease *r,* the common component in term premiums.

Based on this model, it is argued (e.g. D'Amico et. al. 2012:425-26; Joyce et. al. 2012:F279) that QE operations affect term premiums in bond yields by affecting short-run variance in the value of the public's bond portfolio, and/or covariance between the value of the portfolio and the value of bonds at a particular maturity. They do this by changing relative supplies to the public of bonds at various maturities. To reduce the common component in term premiums, a central bank can buy up a lot of long-duration bonds: that reduces the average duration of bonds in arbitrageurs' portfolio and hence sensitivity of the portfolio's value to unpredictable changes in the overnight rate. (In QE literature this is called the "duration channel.") To reduce the term premium at a specific maturity, a central bank can buy a lot of bonds at that maturity, so that bonds of that maturity have less weight in arbitrageurs' portfolio. (In QE literature this is called the "local supply" or "market-segmentation" channel.) Of course, the model should apply just as well to bill discount rates, and to other actions by a central bank that affect variances and covariances in day-to-day asset values.

2.2) Discount houses as risk-averse arbitrageurs

Discount houses arbitraged between the call money rate and the expected overnight return to holding bills: they borrowed overnight at the call-money rate and treated bills as liquid assets that could be bought and sold from day to day. Thus, the daily spread between the call-money rate and the expected overnight return to holding bills would have been smaller (larger) when discount houses demanded more (less) bills at a given spread. Banks did not play this role because, unlike discount houses, banks held bills to maturity.

It is plausible that discount houses were risk-averse in a way approximated by the mean-variance objective function of arbitrageurs in the Vayanos-Vila model. To remain in operation, a discount house needed to maintain an adequate margin of capital, if only to cover haircuts lenders applied to the collateral that secured their borrowing. The Bank of England's haircut for advances to discount houses was 5 percent. According to Sayers (1968:58-59), for a discount house (the "firm"):

> The necessity of always being in a position to provide a margin sufficient to cover any conceivable borrowing at the Bank was thus an important limiting factor in deciding the firm's commitments...A bigger portfolio would..have meant a risk of bigger borrowing at the Bank; this could only have been faced if they had a larger capital in the business...The Bank's rule about the margin of security thus operated seriously, as was intended, as a check on the extension of commitment in the bill market beyond all regard for the capital resources.

Oddly, I have found no reference to haircuts in ordinary call-money lending to discount houses, but if they existed they would have the same effect.

2.3) Hypotheses about term premiums

Suppose a discount house, like an arbitrageur in the model, was averse to day-to-day variance in the value of its assets net of liabilities. Then the term premium for bills would depend on the degree of day-to-day variance in the value of discount house portfolios, and covariance between the value of those portfolios and the value of bills.

The ability of a discount house to rediscount at the Bank or obtain advances there may have lowered variance in the value of its portfolio. Certainly, it decreased covariance between values of relatively short-term assets like bills and value of the portfolio. At times when the Bank was willing to rediscount bills for discount houses, Bank Rate determined a minimum value for bills the Bank was willing to take. A decrease in Bank Rate raised these minimum values and hence decreased covariance of these bills' values with values of other assets. Terms of advances on collateral, which were linked to Bank Rate, had a similar effect. To see this let i^{BR} denote Bank Rate on a daily basis, s^{BA} denote the spread between Bank Rate and the advances rate, and d^{A} be the term of an advance, in days. Then tomorrow's value of an eligible asset will be at least:

(6) $$v_{kt+1} \approx -d_A (i^{BR} + s^A)_{t+1} - E_{t+1} \left[\sum_{\tau=d_A}^{d_k} \left(i + r + r_k \right)_{t+\tau} \right]$$

with the face value normalized to one. (I assume here that a discount house is far enough away from its capital constraint that the cost of the the extra encumbrance on its capital is second-order). This may have little effect on the degree of uncertainty about tomorrow's price of a long-term asset like a government bond. For a bond, the term of an advance is short relative to the asset's remaining duration so the minimum established by (6) would still be strongly affected by changes in expectations of future required returns. But (6) would have a big effect on the degree of uncertainty in the value of a short-term asset like a bill, for which the term of an advance is longer relative to remaining duration.

Thus, I hypothesize that other things equal a decrease in Bank Rate or loosening of other terms of Bank credit tended to lower term premiums in bill rates. This should have been true at all times, not just on a day when discount houses were currently rediscounting or taking advances from the Bank: it was the option to rediscount or take advances *tomorrow* that mattered. In this way my hypothesis differs from the traditional view. In the traditional view, Bank Rate affected markets rates only when

Bank Rate was "effective," that is when discount houses were currently "in the Bank" rediscounting or taking advances.

2.4) Test

To test my hypothesis I run regressions in which the LHS variable is the "*ex post* term premium," that is the spread between the market rate for three-month prime bills on a given day and the *realized* average call money rate over the next three months. The main RHS variable is Bank Rate on that day. I would like to include other terms of Bank credit such as the advances rate, but I have found no time series on any of them. I expect that there was variation in the relationship between the cost of Bank credit, and the degree to which the resulting floor on bill value actually reduced the covariance of bill value with values of other assets. But I have not been able to think of observable variables that could indicate such factors other than the bill rate itself or call money rates (which are already in the regression).

Like other studies of British financial markets in this era, I rely on reports of Bank Rate and market rates in the *Economist.* The *Economist* reported rates prevailing on Friday of each week. I have weekly Friday values for Bank Rate and prime three-month bill rates for all of the era from the 1870s through 1914 (from the Neal and Weidenmier [2005]) database). The *Economist* began to report call money rates every week starting in December 1881. I have not yet collected these for all of the era. The weekly values plotted in Figure 2, which start with January 1890, were kindly provided by Stefano Ugolini. Nishimura (1971) gives monthly averages of the weekly call money rate starting in December 1881. In this draft of the paper, I use these monthly-average data. My LHS variable is the spread between the prime bill rate in the *first week* of a month and the average call money rate over that month and the following two months. On the RHS, Bank Rate is that prevailing in the *first week* of the month. I add quadratic time trends and seasonal dummy variables, as there may have been secular and/or seasonal variation in other determinants of term premiums (such as, in the Vayanos-Vila model, variation in the degree of uncertainty about future overnight rates).

To interpret the results of these regressions, let i_t^B denote the three-month bill rate at the beginning of a month. $\tilde{i}_t$ is the average call money rate over that month. Denote market participants' expected value for a future variable, as of time *t,* with a superscript *e*. The bill rate is:

$$i_t^B = \frac{1}{3}\left(\tilde{i}_t + \tilde{i}_{t+1} + \tilde{i}_{t+2}\right)^e + x_t \tag{7}$$

where *x* is the term premium. The realized three-month average call money rate is:

$$\frac{1}{3}\left(\tilde{i}_t + \tilde{i}_{t+1} + \tilde{i}_{t+2}\right) = \frac{1}{3}\left(\tilde{i}_t^e + \tilde{i}_{t+1}^e + \tilde{i}_{t+2}^e\right) + \epsilon_t \tag{8}$$

where ϵ is the error in market participants' expected value. The *ex post* term premium is:

$$i^B{}_t - \frac{1}{3}\left(\tilde{i}_t + \tilde{i}_{t+1} + \tilde{i}_{t+2}\right) = x_t - \epsilon_t \tag{9}$$

In time-series data, ϵ_t should be uncorrelated with variables known to market participants at time *t* if two conditions hold: first, expectations are rational; second, the distribution of *ex post* outcomes adequately resembles the distribution of outcomes that would have appeared possible to a rational investor *ex ante* - there is no "peso problem". Those are big ifs! But assuming those conditions hold, a regression of the *ex post* term premium on time-t Bank Rate should reveal the correlation between Bank Rate and the term premium. A positive correlation would be consistent with my hypothesis.

To distinguish my hypothesis from the traditional view, I run some regressions in which I attempt to exclude from the sample weeks in which it is likely that discount houses were currently borrowing a lot from the Bank. Unfortunately, I can do this only very roughly. I have been unable to find data on the volume of Bank lending to discount houses through rediscounts and/or advances, so I cannot simply identify and exclude weeks when discount houses were "in the Bank."[16] One may suppose that discount houses borrowed a lot when market short-terrm rates were sufficiently close to the cost of borrowing from the Bank, but it is hard to identify just what the ceiling on short-term rates

[16] Data made available by the Bank of England (Huang and Thomas 2016) give a weekly (Wednesday) figure for "discounts, advances and other securities." This is discounts and advances to discount houses *plus* many other items, including discounts and advances to private customers and banks, and "long-term loans to local councils, school boards and the like" and even "long-term stocks [that is bonds] of railways, governments (outside the U.K.) and municipal corporations" (Sayers 1976:24).

was - what levels, what maturities - given the complexity of Bank credit terms. The best I can do is to exclude months in which the gap between Bank Rate and the prime bill rate was within a predetermined range of Bank Rate (or higher than Bank Rate). For the results I present the predetermined range was half a percent, but other values gave similar results.

According to most literature the Bank of England faced two crises or near-crises within 1881-1914 (e.g. Eichengreen 1992: 49; Davutyan and Parke 1995). One was the Barings crisis in 1890.[17] The other was in the late summer and autumn of 1907, associated with the Panic of 1907 in New York.[18] Around these events there may have been special relationships between term premiums and Bank Rate. To make sure my results are not due to such things I run some regressions omitting the months around these crises.

2.5) Results

Table 1 shows results. The table omits estimated coefficients on time trends (which are significantly different from zero at one percent) and monthly dummies (in most samples, the May dummy is positive and significantly different from zero at one percent). For column (1) the samples included all months from December 1881 through December 1913. The coefficient on Bank Rate is positive and significantly different from zero at the one percent level. The magnitude of the coefficient implies that a one percent increase in Bank Rate tended to increase the bill term premium by more than 30 basis points. If the time trend terms and monthly dummies were not included on the RHS, the

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[17] At the beginning of November 1890 it became known that Barings Bank was potentially insolvent due to large holdings of bad South American bonds. The Bank organized and partially funded a takeover of Barings' operations by other banks for orderly liquidation. Clapham (1944: 335) judged that "everything was so quick, so decisive, and so highly centralized that there was no true panic, on the Stock Exchange or anywhere else, no run on banks or internal drain of gold." But there was an extraordinary increase in rediscounting at the Bank in November 1890, when bills with Barings' acceptance began to "pour in" (Clapham 1944:331).

[18] In 1906 large exports of gold to the U.S. spurred the Bank to take its usual steps to raise bill rates - draining reserve supply, hiking Bank Rate and other terms of lending to discount houses. It also employed gold devices and persuaded the Bank of France to buy British bills (Sayers 1976:55-56). In August 1907, in response to the approaching Panic of 1907 in New York, London banks "took fright and dropped their taking of new bills," driving up bill rates and driving discount houses to borrow from the Bank even though there had been "no export of gold, no seasonal disturbance of the Bank's balance sheet and, in the first stages, no restrictive action by the Bank" (Sayers 1976:57).

coefficient on Bank Rate was still significant at one percent, and of about the same magnitude. Figure 3 is a scatterplot of the realized spread against Bank Rate. The positive correlation is obvious.

Of course, this I cannot prove that this positive correlation indicates a causal relation, but I can rule out one obvious alternative explanation: that the term premium was (for some reason) positively related to the general level of short-term rates (not Bank Rate), while the Bank set Bank Rate in line with short-term rates. To check this, for column (2) I added the previous month's average call money rate to the RHS. (The lagged bill rate would not be suitable for this purpose, as it directly incorporates the term premium.) The coefficient on Bank Rate remains significant at one percent; the coefficient on the lagged call money rate is not. Columns (3) and (4) show results excluding crisis periods. They are about the same as those in (1) and (2). Finally, for (5) and (6) I also excluded months when the bill rate was within half a percent of Bank Rate. Coefficients on Bank Rate remain positive and significantly different from zero at one percent, though their magnitudes are smaller.

For the standard errors and p-values in Table 1, I treated each month as an independent observation. That is correct only if the null hypothesis is that there is no relationship between any of the interest rates. The null hypothesis might instead be that Bank Rate is unrelated to the realized spread, but that otherwise bill rates are related to expected future call money rates, expectations are rational and there is no peso problem. In that case, the null hypothesis includes a specific pattern of correlations across residual terms in adjacent observations. (Some of the future call-money forecast error included in one month's ex-post term premium is included in those of the two following, and two previous months). In this draft of the paper I do not have results from a specification allowing for this. I did, however, roughly estimate the degree to which it could possibly increase the standard errors (by assuming that there were effectively only four observations in a year). The coefficients on Bank Rate are all still significantly different from zero at one percent.

3) How the Bank influenced the call money rate

Now I turn to determination of the call money rate. I begin by reviewing current models of overnight-rate determination. In them the nature of reserve demand depends on the mechanics of the interbank payments system, reserve requirements if there are any, and the nature of the cost to a bank that suffers a shortfall in its reserve account. To apply the models to pre-1914 Britain, I return to accounts by contemporaries and economics literature for details about the process of clearing interbank payments in London, the Bank's practices with respect to banks' reserve accounts, and reserve supply. I argue that the cost to a bank of running a shortfall in its reserve account was most likely related to the expected value of call money rates in the near future. Under these conditions, the models suggest that banks' demand for "nonborrowed reserves" was negatively related to the spread between the call money rate and bill rates, taking the latter as a stand-in for expected future overnight rates. To test these hypotheses I regress the call money rate on nonborrowed reserve supply, the bill rate and Bank rate.

3.1) Models of reserve demand and determination of the market overnight rate

Entering the 2008 financial crisis most central banks paid banks interest on "reserve accounts," that is accounts that banks held at the central bank and used to make interbank payments. Some central banks required banks to maintain predetermined minimum balances - "reserve requirements" - in their central-bank reserve accounts on average over multi-day "maintenance periods." Nearly all central banks freely granted overnight credit to banks to cover overdrafts in their reserve accounts or shortfalls from required minimum balances.

In the common understanding of these systems, the cost of overnight credit from the central bank determines a ceiling on the market overnight rate: at some point a borrowing bank would rather take central bank credit, by deliberately running an overdraft, than borrow at a high market rate. The interest rate paid on reserve balances is a floor on the market rate: no lending bank would take less for an overnight loan.[19] Between the floor and ceiling the market rate was determined by the interaction between the supply of "nonborrowed" reserves, that is reserves *not* lent through the central bank's overnight credit facility, with banks' demand for nonborrowed reserves, which was negatively related to the market overnight rate.

[19] The floor can be "soft" - the market rate can fall a bit below the reserve interest rate - if there are institutions other than banks that hold reserve accounts but are not paid interest on them, as the Fed discovered after 2008 (Craig and Millington 2017).

In a system with multi-day reserve requirements, on early days of a maintenance period reserve demand is negatively related to the spread between the current overnight rate and overnight rates expected to prevail later in the same maintenance period. That is because a bank meets a multi-day reserve requirement at lowest cost by holding more (less) reserves on days within the period when the overnight rate is relatively low (high) (Hamilton, 1996; Furfine, 2000; Demiralp and Jorda, 2002). Thus, holding fixed expected future overnight rates, an increase (decrease) in nonborrowed reserve supply tends to decrease (increase) the market overnight rate.

In later days of a maintenance period, or if there are no reserve requirements, reserve demand is still negatively related to the market overnight rate, but for different reasons. In most interbank payment systems a bank cannot forecast exactly how long it will take some types of payments to be credited to (debited from) its central bank account. Thus, a bank that aims to hold a balance of a given size in its reserve account after the central bank finishes clearing payments at the end of a day or reserve-account maintenance period is uncertain about the balance that will actually be in the account. Aiming to leave a larger balance in the reserve account reduces the probability that the realized balance will be too small - below zero or the reserve requirement - forcing the bank to take an overnight loan from the central bank to cover the shortfall. A bank trades off this benefit of holding a larger reserve balance against the cost of holding funds in its reserve account, which is the spread between the market overnight rate and the interest rate paid on reserves. The resulting demand for reserves is negatively related to the market overnight rate, positively related to the reserve-account interest rate and positively related to the cost of central-bank credit to cover a reserve shortfall. Recent models of this include Whitesell (2006), Ennis and Keister (2008).

Along the lines of those models, let $\overline{i}$ denote the cost of overnight credit from the central bank. $\underline{i}$ is the interest rate paid on excess reserves. $\overline{i_e}$ is interest paid on required reserves, perhaps but not necessarily equal to $\underline{i}$. R is the balance a bank aims to have in its reserve account at the end of the day or maintenance period, when payments have been completely cleared. The balance actually left in the account after final clearing is $R+\delta$, where δ is the unpredictable component of net payments. A bank suffers a shortfall in its account if $R+\delta < Z$, where Z is equal to the portion of the reserve requirement that was not covered on earlier days of the maintenance period, or zero if there is no reserve requirement. A bank has a probability distribution for δ with a minimum value $\underline{\delta}$, a maximum $\overline{\delta}$, a c.d.f. *F{X}* , a p.d.f. *f{X}* and the inverse of the c.d.f. *G{X}*. A bank is approximately risk-neutral at the margin with respect to its choice of *R*. It chooses *R* to minimize the expected value of the sum of the opportunity cost of holding reserves and the cost of borrowing from the central bank to cover a reserve-account shortfall, net of interest earned on reserves, which is:

$$(10) \qquad iR + \int_{\underline{\delta}}^{-R+Z} \overline{i}\,(Z-R-\delta) f\{\delta\} - \int_{-R+Z}^{\overline{\delta}} \underline{i}\,(R+\delta-Z) f\{\delta\} - \overline{i}_e Z$$

Minimizing (10) gives reserve demand:

$$(11) \qquad R^D = Z - G\left\{\frac{i-\underline{i}}{\overline{i}-\underline{i}}\right\} \quad where\;\; G'\{X\} > 0 \;\; for \;\; \underline{i} \le i \le \overline{i}$$

which implies that reserve demand is negatively related to the overnight rate, positively related to $\underline{i}$ and $\overline{i}$. Reserve demand also depends on a bank's perceived distribution for the unpredictable payments component δ . It is often observed that banks’ reserve demand increases at times of high payments volume (e.g. at quarter-ends). In terms of this model, that is explained by a relationship between payments volume and the distribution for δ . Many studies of monetary aggregates (e.g. M1) assume there is a long-run relationship between reserves and the volume of deposits in banks - a “reserve ratio” - even in systems without reserve requirements (e.g. Capie and Wood 1996). In this model, that is true if deposit volume is related to the distribution for δ .

The sum of R^D across all banks is “nonborrowed reserves,” that is total balances in reserve accounts *before* any borrowing from the central bank to cover shortfalls. On the simplifying assumption that all banks are identical, setting R^D equal to nonborrowed reserve supply per bank R^S determines the market overnight rate:

$$(12) \qquad \begin{aligned} &i = \underline{i} + F\{Z-R^S\}(\overline{i}-\underline{i}) \quad for \;\; Z-\overline{\delta} \le R^S \le Z-\underline{\delta} \\ &i = \underline{i} \quad for \;\; Z-\underline{\delta} < R^S \\ &i = \overline{i} \quad for \;\; R^S < Z-\overline{\delta} \end{aligned}$$

Note that the market rate resulting from any given nonborrowed reserve supply depends on the values of $\bar{i}$ and $\underline{i}$.

To keep the market overnight rate at a target i^T, the central bank can set $\underline{i} = i^T$ and $R^S \geq Z - \underline{\delta}$: this is the "floor" system adopted by many central banks (including the Fed) since 2008. For the "tunnel" or "corridor" system common before 2008, the central bank sets $\bar{i}$ above the target i^T by a fixed margin (e.g. 50 basis points) and $\underline{i}$ at the same margin below the target (that is $\bar{i} = i^T + s$, $\underline{i} = i^T - s$). Central bank staff then use open-market operations to keep R^S at the value that holds the market rate in the middle of the corridor. In either of these systems, changes in the target can be implemented without systematic adjustments to reserve supply (Woodford 2000; Keister, Martin and McAndrews 2008).

With small changes, the same model can describe various other systems of monetary policy implementation.

In the early 1990s New Zealand's central bank had a system which was not obviously a corridor, but operated like one. It had a target for the market overnight rate, but it set $\bar{i}$ and $\underline{i}$ equal to fixed margins around the market rate for bills, not the overnight-rate target. As signalled changes in the central bank's overnight-rate target affected expectations of future overnight rates, they affected bill rates, hence reserve demand in such a way that the market rate usually followed the signalled change in the target with no systematic change in reserve supply. To describe this set $\underline{i}$ and $\bar{i}$ equal to a fixed margin around the the expected value of average future overnight rates prevailing through the maturity of a bill. This is the model of Guthrie and Wright (2000), who referred to the effect of signalled changes in the target on market overnight rates as "open-mouth operations."

In the decades from the 1950s through the 1990s, the Federal Reserve system paid no interest on reserves. The interest rate it charged for loans to cover reserve shortfalls, the "discount rate," was usually set *below* market overnight rates. The market overnight rate could exceed the discount rate because "discount credit" was strictly rationed. Many economists believed that the rationing system was equivalent to an extra "nonpecuniary" cost of discount credit, perhaps a fixed cost per dollar borrowed, perhaps a marginal cost that increased with the amount borrowed. To describe this set $\underline{i} = 0$ and $\overline{i}$ equal to the discount rate plus the extra cost: this is the model of Poole (1968). It implies that reserve demand is negatively related to the ratio of the market overnight rate to the marginal total cost of discount borrowing, that is the discount rate *plus* the marginal nonpecuniary cost. Holding the discount rate fixed, an increase (decrease) in nonborrowed reserve supply tends to decrease (increase) the market overnight rate. Holding nonborrowed reserve supply fixed, an increase (decrease) in the discount rate tends to increase (decrease) the market overnight rate.

In the 1990s the Federal Reserve was targeting the overnight rate. It announced changes in the target or signalled them to financial-market participants. Surprisingly, most changes in the target were successfully implemented just by announcing or signalling them - by open-mouth operations - without adjustments to nonborrowed reserve supply *or* the discount rate (not only within early days of a maintenance period, but across maintenance periods) (Friedman and Kuttner 2011). Hanes (2014) argues this can be explained as the outcome of the particular type of discount-lending credit rationing imposed on most banks in the 1990s. A bank that borrowed from the "discount window" was not allowed to borrow again for a while. That meant the nonpecuniary cost of discount borrowing was the loss of an option to borrow in the immediate future. A bank that had used up its borrowing option had to hold a large reserve balance to ensure it would not suffer a reserve shortfall. Thus, the value of the option was the expected opportunity cost of holding more reserves in the near future - the expected near-future overnight rate, which was the perceived target. Thus, an announced or signalled change in the target affected the nonpecuniary cost of discount borrowing, hence the market overnight rate at any given reserve supply. To describe this set $\underline{i} = 0$ and $\overline{i}$ equal to the discount rate plus an extra cost linked to the expected future target.

3.2) Reserve supply, clearing and reserve demand in pre-1914 London

Reserve supply

As noted above, the Bank of England had many ways to add to or drain reserve supply. Importantly, however, Bank policymakers did not use reserve-supply operations to influence or stabilize market interest rates, apart from actions to reinforce effects of an international gold drain.

Except when the Bank was losing gold to an external drain, policymakers did not drain reserves (Sayers 1936: 47-48). They did not deliberately add reserves with open-market debt purchases or repos. They did not act to counteract factors that affected reserve supply, even ones that were well-understood at the time. One of these was seasonal currency demand. Another was changes in the balance in the Treasury's account at the Bank (Sayers 1936: 24, 133-35). A payment into (out of) that account subtracted from (added to) the supply of high-powered money to the public. Over the course of a year there were big swings in the Treasury balance due to the timing of expenditures and payments on Treasury debt *versus* revenues and receipts from sales of new debt. Contemporaries knew that the resulting swings in reserve supplyaffected market interest rates (e.g. Clare 1902: 26-27; Sayers 1936:24-25). But the Bank made no effort to accommodate them. At times of high demand for currency or high Treasury balances, the Bank simply allowed short-term rates to rise and provided more advances and/or rediscounts to discount houses that came into the Bank.

The mechanics of clearing and opportunity cost of holding reserves

The process of clearing interbank payments in pre-1914 Britain appears to match two key elements of models following Poole (1968): a bank was uncertain about the exact balance that would be left in its reserve account after final settlement; and the opportunity cost of holding reserves was the market overnight rate, that is the call money rate.

As mentioned above, there were bankers' clearing houses in London and several other cities. Generally, British clearing houses cleared payments at the end of every business day and presented a member bank with a net debit or credit in the late afternoon. The member bank then settled it with its reserve account held in the local office of the Bank of England.[20] I focus on London because contemporaries wrote a lot about the London clearing house, and the Bank of England has published time series of banks' reserve balances for balances held at the Bank's main, London office, for all weeks in the gold-standard era. Their series on balances held in the Bank's other branches begin in 1910. I hope that what goes for the reserve demand of London-headquartered banks goes for total reserve demand. In any case, the London clearing house dwarfed the others in volume, and payments between banks in different cities, or in cities without clearing houses, were made through London (that is through accounts held in London correspondent banks [Francis 1888: 210; Seyd 1872: 52,63]).

Member banks of the London clearing house were called "clearing banks." Around 1900 there were about 25 of them (Clare 1902: 29). London banks that did not belong to the clearing house made payments through accounts held with clearing banks, or reserve accounts at the Bank of England (Francis 1882: 192).

A clearing bank sent to the clearing house all payment orders on other member banks (e.g. checks, drafts, due bills of exchange issued by customers of the bank) (Matthews 1921: 26). All member banks' head offices were "within five minutes walk of the Clearing House" (Matthews 1921: 25), which was on Lombard Street, steps from the Bank of England. The Bank of England was also a member of the clearing house but only “on one side”: it sent in claims for payment on clearing banks but paid claims on itself directly into a bank's Bank of England account (Seyd 1878:55; U.S. National Monetary Commission 1910:11). Messengers carried the orders. In the morning they carried over orders held from the previous day, orders that had come in from branches and claims for payment on bills in a bank's portfolio that had come due. At the clearing house orders were totalled and netted (in the "morning clearing") to be carried forward into the afternoon (Matthews 1921: 30). In the afternoon banks sent in:

> cheques, bills etc. that have been received..during the day, and towards the closing time there is a constant running of clerks to and from the Clearing House..the doors of which are closed at a stated time. When the doors are closed there is no means of obtaning payments for the cheques shut out until the next day...On Stock Exchange Settling Days and other occasions when the work is heavy, it is no uncommon thing near closing time to see the runners rushing down Lombard Street as if their lives depended on it (Matthews, 1921: 27).

[20]Manchester, Liverpool and Birmingham were the most important clearing houses outside London. Practices of provincial clearing houses are described by Matthews (1921:139-166) and Barnett (1882).

Closing time was a bit before 4:00 in the 1870s-80s (Seyd 1878:64; Francis 1888:182), a bit after 4:00 in later years (Matthews 1921: 43). The Bank of England sent in all its claims for the day just before closing time, at about 3:45 (Francis 1888:182).

When the doors were closed clerks finished sorting the afternoon claims and added them to those sorted in the morning. Then the day's claims on a bank were carried back to the bank. A bank was given one hour to examine the claims, identify any it did not want to pay, and carry challenged claims - "returns" or "unpaids" - back to the clearing house (Matthews 1921: 32,43). "The majority of these returns comprise Bills, for some irregularity in the endorsement, or want of funds...The returns of Cheques are less numerous, and they are mostly connected with technical irregularities" (Seyd 1872: 50). Challenged claims were "deducted at once from the balances" (Seyd 1878: 51) to be resolved on the following day. A bank then paid off a net debit or took payment for a net credit with its Bank of England reserve account.

> When the balance sheet has been so far completed as to include the last unpaids..it remains only to strike the balance...If it is a pay balance, the clerk in charge fills up an order to the Bank of England to transfer from the account of his bank to the Clearing House account at the Bank of England the amount this bank is liable to pay...If on balance the bank has a claim against the Clearing House, the clerk in charge makes out a transfer for the amount of his claim from the Clearing House to the account of his bank at the bank of England (Matthews p. 34).

The total quantity of reserve account balances at this time included funds the Bank had provided to discount houses that day through rediscounts or advances. Until 1894 a discount house could apply for a loan or advance up to 3:30 in the afternoon; starting in 1894 the closing time was 2:30 (Sayers 1976: 37). It would receive a check drawn on the Bank. The discount house took this check to its clearing bank and the bank presented the check to the Bank of England for payment at the end of the same day, receiving an immediate credit to its own Bank of England account (Seyd 1878:55; U.S. National Monetary Commission 1910: 11; Withers 1910: 63).

A bank's staff could not have been certain about its net clearing house balance at the end of the day. A claim might or might not make it into the clearing house by 4 o'clock. A payment-in might be challenged by the paying bank and held over to the following day, at least.

Staff could, however, aim at a target net balance by adjusting the volume of the bank's call money lending to discount houses. According to all contemporaries, a bank let these loans run off when it needed cash for payments or to increase the balance in its reserve account (Clare 1902:44; Spalding 1930:121-22). Payments associated with call money loans to discount houses were cleared within the same day: "When a banker is lending, he either gives the broker [discount house] his cheque drawn on the Bank of England or lets the broker draw a check on him..if a loan is called in, the broker hands the lending banker his cheque on his own banker, and receives back his security" (Spalding 1930: 133). This was just about the *only* thing bank staff could do to affect the bank's reserve balance by the end of the same day. Recall that securities transactions were cleared only twice a month, and short-term loans to bond and stock brokers were usually for the same two-week span. Payments associated with bill transactions were cleared at the end of the same day, but recall that banks never sold bills.

The cost to a bank of a reserve-account overdraft

What would happen if a bank ended up with a net debit in final settlement, and the balance in its Bank of England reserve account was not enough to cover the debit? Unfortunately, I have not found a clear answer to this question.

In 1860, prior to the era I examine, the Bank would have automatically covered such an "overdraft" with an overnight loan to the bank, collateralized by securities the bank had previously lodged with the Bank (just like a "discount" or "primary credit" loan by the Federal Reserve). According to Holland (1910: 281),

> in 1860 we find the following correspondence taking place between..the chairman of the committee of clearing banks, and the Bank of England: "Referring to our recent communications on the subject of the settlement of the bankers' clearing, I beg to say, to prevent mistake, that I understand that the cashiers of the Bank of England will have the authority..in case of any banker's account appearing to have overdrawn in the clearing to overpay the same, to an extent

> previously agreed upon, on the deposit of any of the undermentioned securities, viz, exchequer bills, India bonds or debentures, Turkish guaranteed 4 per cent stock, and commercial bills. The advance to be repaid by such bankers in the course of the next day." To this the governor replied: "You have rightly interpreted what passed at our interview yesterday, and I and my deputy will be prepared to issue our instructions to the chief cashiers to act in the sense mentioned."

But contemporaries are oddly silent about the practice prevailing in later years.

In a study of clearing bank records, Goodhart (1972) found evidence that the Bank continued to follow its 1860 policy. In the 1890s one bank lodged securities at the Bank to serve as collateral against any "temporary," "accidental" overdraft" (fn 47 p. 109). Other evidence he found suggested that "most banks had made standing arrangements with the Bank" for loans at short notice, lodging securities there to serve as collateral. Goodhart could not determine whether this was because banks wanted "cover for temporary overdrawing," or "help in times of need, when they were under extreme pressure" (p. 111) - that is, lender-of-last-resort help. But making advances to cover overdrafts would be consistent with the Bank's policy toward accounts of private customers: "although the accounts are not allowed to be overdrawn, it is always ready to discount satisfactory bills for its customers and to make advances on certain classes of securities" (Francis 1888: 191-92).

What rate did the Bank charge for last-minute advances to banks? I have found no evidence on this. Perhaps the Bank treated them like advances to discount houses. In that case the rate would be Bank Rate or Bank Rate plus a differential. Perhaps the Bank treated them like advances to private customers. In that case the interest rate rate would be based on a market rate, probably a bill rate. (That is what the Bank seems to have meant by "market rate" with respect to private customers.)

Another possibility is that they were treated like the last-minute loans a discount house could receive from its clearing bank. A discount house that failed to arrange sufficient financing from the market or the Bank of England in the afternoon could cover the shortfall with a line of credit from its clearing bank that could be drawn on at the very end of a day. This was essentially permission to run an overdraft in its clearing bank account. Such credit was called "privilege money." The rate charged for privilege money was not high. In at least one case the rate charged was just "the Discount Houses' advertised rate for call loans." But privilege money was subject to a form of rationing. It was a policy of clearing banks that such credit was not to be used "for profit," or "habitually" (Sayers, 1968: 54-55). Presumably, a discount house that used privilege money too frequently could lose the privilege.

Informal reserve requirements?

There was no regulatory reserve requirement of any kind. Consistent with that fact, some writers describe banks' reserve demand as being governed entirely by needs to clear payments. A contemporary Bank of England official was reported to have said that reserve account balances were "the minimum amounts required for the purposes of the bankers' clearing" ("Banker," 1905). Sayers (1957: 269) claimed that "In Lombard Street the banker had to think of big differences in the Clearing; subject to this, a Lombard Street office could maximise the interest to be earned on the bank's resources." Certainly, banks' demand for reserve balances increased at times when the volume of payments was especially high, such as quarter ends and stock-exchange settlement days (Withers 1910: 14, 15; Clare, 1902: 43; Matthews 1921:81). That is consistent with payments-related reserve demand, as illustrated by the model above.

Most contemporaries, however, claimed that bankers' balances were "out of all proportion to the amounts required by the necessities of clearing" (Withers 1910: 283), in such excess that overdrafts simply never occurred (Holland 1910:281). Goodhart (1972: 109) judged that balances were so large relative to payments flows that overdrafts must have been extremely unlikely, at least.

> The normal practice, it seems, was for banks (the decision being taken at the highest level - the board of directors) to choose either a minimum balance or a target level for the balance to be held at the Bank...In the London and County Bank the amount of the minimum balance to be kept at the Bank was laid down in standing orders. These minimum balances, which the head office managers were required to keep, were very greatly in excess of the balances required to maintain a continuing credit balance in the face of the normal fluctuations, up and down, resulting from the clearing process...Yet the balances held by the banks were quite frequently very close to the minimum which they desired to maintain (p. 108-09).

Why did bank directors choose to maintain such high minimum balances? For a few days each year, one motive was "window dressing" a bank's reported balance sheet. There was no regulatory requirement for a bank to publish balance sheet information but twice a year, for one day in June and one day in December, banks published accounts that listed the amounts held in cash or at the Bank. In 1891 a majority of clearing banks began to publish statements for one day at the end of each month, "and it thus followed that on one day at the end of each month the banks showed as proportion of cash to liabilities which they considered sufficiently adequent to stand the light of publicity" (Withers 1910:27). "The desired ratio of cash to deposits" was about ten percent in the early 1890s. By the eve of the First World War "15 percent was clearly regarded as the proper ratio to exhibit to the world (i.e. if a bank actually worked to less, it would window-dress to 15 percent in its published statements" (Goodhart 1972: 114). But this cannot explain why banks maintained such high reserve balances between statements; banks could and did let call loans run off just at the end of the month to boost cash for one day (Spalding 1930:120). And some clearing banks did not publish monthly statements.

Goodhart speculated that banks maintained high balances because the Bank of England wanted them to, and there was an implicit threat from the Bank that a bank that failed to do so would not receive lender-of-last resort help in a crisis. This informal requirement was not a matter of prudential regulation, but simply to increase the profits of the Bank by giving it more funds to employ in profitable investment (1972: 105, 112). This would be consistent with the Bank's behavior toward private account-holders: they were required to maintain minimum balances to ensure an account was sufficiently profitable to the Bank (Francis 1888:179).

3.3) Hypotheses

Based on this evidence and the models, what would one hypothesize about reserve demand? Generally, daily reserve demand should have been negatively related to the day’s market call money rate, which was the opportunity cost to a bank of holding reserve balances.

One can rule out the possibility that there was no informal reserve requirement *and* the Bank allowed a bank to cover a reserve-account shortfall with unrationed advances at a rate close to market short-term rates. This is not consistent with the apparent fact that banks kept such large balances in their reserve accounts that shortfalls would occur very infrequently. In the reserve-demand model, setting the reserve requirement and interest on reserves at zero, the probability that a bank overdraws its reserve account and has to borrow is:

$$F\{-R^D\} = i / \bar{i} \tag{13}$$

where $\bar{i}$ is the cost to cover the marginal pound of shortfall. If $\bar{i}$ is close to the market overnight rate i then shortfalls occur frequently. Not true.

So, either there was either a type of informal reserve requirement as Goodhart believed, or the cost to a bank of covering a shortfall was high relative to the usual level of the call-money rate. Or both.

The cost of advances from the Bank could have been high if that cost was Bank Rate plus a large margin. In that case, an increase in Bank Rate would tend to increase reserve demand. The advances cost could also have been high if there was a rationing rule that limited the frequency of a bank's borrowing. In that case, the largest part of the borrowing cost would be the loss of an option to borrow in the near future. As in the 1990s U.S., a bank that had used up its borrowing option would have to hold a large reserve balance for a while to ensure it would not suffer a reserve shortfall. The value of the option would be the expected opportunity cost of holding more reserves in the near future. In this case, therefore, an increase in expected near-future call money rates would tend to increase reserve demand.

Under an informal reserve requirement, a bank that let its reserve fall below the required level on a day would need to make up for it by holding more in the account at some point in the near future. Possibly, a bank that held more than the required level on a day could hold less later on. (It could not mean that a bank had to hold a required balance level at all times: because aggregate reserve supply fluctuated, actual balances must be sometimes above, sometimes below requirements.) If so, then the effective cost to a bank of of letting its reserve balance fall below the required level was the expected opportunity cost of more reserves in the future. Again, an increase in expected near-future call money rates would tend to increase reserve demand.

Finally, in any of these cases, reserve demand could increase with the volume of deposits in banks. This would be true if a bank's informal reserve requirement increased with its deposits. In the absence of an informal reserve requirement, it could be true if deposit volume affected the distribution for the unpredictable component in daily settlement (δ).

I hypothesize that reserve demand can be generally described as:

(14) $$Ln(R_t^D) = -a\,i_t \ + \ b\,\hat{i}_t + c\,Ln(D_t) + \epsilon_t^{RD}$$

i is the call money rate. $\hat{i}$ is either Bank Rate plus a margin *or* expected near-future overnight rates. D is deposits. ϵ^{RD} represents other factors affecting reserve demand. The market call money rate was:

(15) $$i_t = \frac{b}{a}\ \hat{i}_t - \frac{1}{a}\ Ln(R_t^S) + \ \frac{c}{a}\ Ln(D_t) \ + \ \frac{1}{a}\,\epsilon_t^{RD}$$

Reserve supply R^S included reserves created as a result of Bank lending to discount houses through rediscounts and/or advances, because those funds added to the reserve balances banks used to cover clearing house debits at the end of the day. It would not include Bank advances to banks to cover post-clearing reserve-account overdrafts.

3.4) Tests

To test this hypothesis I examine relations between the available measure of reserve quantity, the current call money rate and the discount rate *versus* the prime bill rate. I take the prime bill rate to indicate the expected future call money rate, subject to a possible relationship between the discount rate and the bill rate term premium for which I presented evidence above. I want to establish whether reserve demand was indeed negatively related to the call money rate, and positively related to either of the other two interest rates, Bank Rate or the bill rate.

The available measure of reserve quantity is total balances held by banks in the Bank's main office. Correctly, this includes funds supplied to discount houses through Bank rediscounts and/or advances. Incorrectly, it may include Bank advances to banks to cover post-clearing reserve-account overdrafts.I can, however, take changes in the available measure as an *indicator* of changes in

R^S because (under the hypothesized model) R^S is positively related to the sum of R^S and post-clearing credit. The expected value of a bank's reserve-account shortfall is:

(16) $$B = \int_{\underline{\delta}}^{-R^S+K} (K - R^S - \delta) f\{\delta\}$$

Across many similar banks, B would be the *average* shortfall covered by post-clearing advances from the Bank. Changes in ($R^S + B)$ are positively related to changes in R^S :

(17) $$\partial(R^S + B) / \partial R^S = (1 - F\{-R^S\}) = \frac{\bar{i} - i}{\bar{i}} > 0$$

The observable relationship between interest rates and reserve quantity will of course reflect the reserve supply process as well as demand. Under some conditions with respect to reserve supply, a regression in the form of (14), with reserve quantity on the LHS and the three interest rates on the RHS, should reveal the nature of reserve demand. The required conditions are that the array of interest rates was determined by factors uncorrelated with the unobservable reserve-demand disturbance ϵ^{RD} , annd reserve supply was perfectly elastic at these rates. Some might argue that these conditions are plausible for the classical gold standard era. A common view of that era is that interest rates subject to international arbitrage were governed by uncovered interest-rate parity (UIP) in a world of perfect capital mobility. That implies London bill rates were equal to a general level of bill rates prevailing across all financial markets in the gold-standard world, plus (minus) a limited differential equal to any expected future depreciation (appreciation) within the gold points (Bordo and McDonald, 2005). It also implies that international gold flows immediately accommodated changes in high-powered money demand at that bill rate. The London call money rate was not subject to international arbitrage in the same way. But one might argue its spread against bills was determined by factors largely unrelated to current reserve demand.

If perfect capital mobility did *not* hold then a regression in the form of (15) should be more informative. Under imperfect international capital mobility UIP would fail but international investment flows, hence international gold flow would still respond to changes in the London bill rate relative to expected returns on foreign investments. Recall that the Bank of England re-enforced money-supply effects of gold flows with other actions affecting reserve supply. Thus, one would expect changes in the bill rate to have a positive effect on reserve supply. But, again because the call money rate was not a focus of international arbitrage, changes in the call money rate would *not* have a direct effect on reserve supply. Thus, reserve supply could be described as $Ln(R^S) = d\, i^B + \epsilon^{RS}$. The last term ϵ^{RS} represents factors affecting international gold flows other than the London bill rate (such as foreign bill rates, the balance of trade), and domestic reserve-supply factors such as currency demand and Treasury balances at the Bank. As long as ϵ^{RS} was not too correlated with ϵ^{RD} , a regression in the form of (15) should reveal the nature of reserve demand, and how the call money rate was determined.

For both types of regression it is important to include the volume of deposits on the RHS, because reserve demand may have been affected by deposit volume *and* changes in the discount rate probably had a fairly direct effect on deposit volume. Recall that London joint-stock banks indexed their collusively determined time deposit rates to Bank Rate (Figure 1). Presumably an increase in the time deposit rate attracted more deposits into banks, other things equal. Taylor and Wood (1996) observe such a relationship in a study of British M3 over 1870-1914. Thus, omitting deposits from the RHS would mean omitting a variable that positively affects reserve demand and is positively correlated with Bank Rate. That could create a positive coefficient on Bank Rate in either (14) or (15), even if Bank Rate did not really affect reserve demand.

In this paper I do not take a stand on whether UIP held in the gold standard era (though I believe there is strong evidence it did not). I run both forms of regression. Fortunately, both give the same answers to the questions I want to answer.

3.5) Results

Call money rate on LHS

Table 2 shows results of the regressions with the call money rate on the left-hand side. Capie and Webber (1985: Table III.3) give careful estimates for London bank deposit volume from 1870 through 1914, at the end of June and the end of December of each year, based on the balance sheet information banks released only for those times.

For panel A, data are semiannual matching the deposit data. The LHS variable is the monthly average call money rate in June and December. RHS variables are monthly-average prime bill rate and Bank Rate, the log of London monthly-average bank reserves (as defined above) and the log of London joint-stock bank deposits (on one day toward the end of the month). Also on the RHS were quadratic time trend terms and a seasonal dummy; I do not report coefficients on these but the time trend terms were generally significant.

For column (1) the sample included all semiannual observations from 1881 through 1913. Both the bill rate and Bank Rate were on the RHS. The estimated coefficient on log reserves is negative and significantly different from zero at one percent. The log deposits coefficient is positive and significant at 5 percent, consistent with a positive effect of deposits on reserve demand. The bill-rate coefficient is positive, significant at one percent, practically equal to one. The Bank Rate coefficient is not significantly different from zero, Its sign is negative, consistent with a hypothesis that the bill rate is serving as a proxy for expected future overnight rates and the bill-rate term premium was positively related to Bank Rate. (When Bank Rate is higher, true expected future call money rates are higher relative to the bill rate, so the coefficient on Bank Rate is negative.)

For column (2), Bank Rate was excluded from the RHS. This does not reduce the R^2, but it does reduce the magnitude of the bill rate coefficient. Again that suggests the bill rate is a proxy for expected future call money rates: it is a worse proxy (more measurement error) when the regression does not control for the effect of Bank Rate on the term premium. (3) replaces the bill rate with Bank Rate. Here the Bank Rate coefficient is positive and significant. No surprise: Bank Rate is strongly correlated with the bill rate (see Figure 2). But the R^2 is smaller than in (2) and (3).

Panel B of Table 2 shows results of regressions on monthly data. The log deposits variable is a linear interpolation between the true log values for June and December. The interpolated value indicates the *long-term trend* in monthly log deposits. The deviation of true monthly log deposits from long-term trend is an omitted variable in the regression. Presumably, this omitted variable was positively correlated with Bank Rate for the reason discussed above. This would tend to create a positive coefficient on Bank Rate in these regressions. The results in Panel B are consistent with that.

In columns (1) and (4), the Bank Rate coefficient is positive and significantly different from zero at conventional levels. But it is much smaller in magnitude than the coefficient on the bill rate, and leaving out the bill rate still tends to reduce the R^2 , while leaving out Bank Rate does not.

Log reserves on LHS

Table 3 shows results of regressions with log reserves on the LHS. Coefficients are generally consistent with a hypothesis that reserve demand was negatively related to the call money rate, positively related to the bill rate. When the bill rate and Bank Rate are both on the RHS, the bill rate coefficient is positive and significantly different from zero at one percent; the Bank Rate coefficient is not significantly different from zero. Replacing the bill rate with Bank Rate, in (3) versus (2) and (6) versus (5), reduces the magnitude of the coefficient on the call money rate.

4) Conclusion

The policy implementation system of the pre-1914 Bank of England gave it influence, or at least potential influence, over both the overnight call money rate and bill rates. The call money rate was affected by reserve supply. The bill rate mainly reflected expected future call money rates, but the term premium in the bill rate was affected by Bank Rate and other determinants of the cost of Bank credit to discount houses. Given that the Bank was maintaining more-or-less fixed foreign exchange rates, the direction of causality from one variable to the other depended on the nature of international capital mobility. In this paper I avoided taking a stand on that.

Compared with today's implementation systems, the pre-1914 Bank's system was interesting in a couple of ways. The cost to a bank of running a shortfall in its reserve account was linked to expected future overnight rates. Theoretically, a change in expected future call money rates would affect reserve demand and the market overnight rate resulting from any given reserve supply. In this way the system was similar to those of New Zealand and the United States in the 1990s which gave rise to the phenomenon of "open mouth operations." If the pre-1914 Bank had been targeting interest rates with flexible exchange rates, open mouth operations would have worked for the Bank, too.

Alongside the rules that determined the cost of a reserve-account shortfall, the Bank operated a standing facility that provided credit to securities dealers (discount houses) for terms of two weeks (advances) to two months (rediscounts). The cost of credit from this facility was a tool by which the Bank could influence term premiums on bill-maturity instruments. The Fed set up similar facilities to operate during the financial crisis. The example of the pre-1914 Bank suggests that such longer-term lending facilities could be a useful tool at all times.

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Figure 1 Bank Rate and London joint-stock bank deposit rate, January 1880 - December 1913
Monthly, end of month

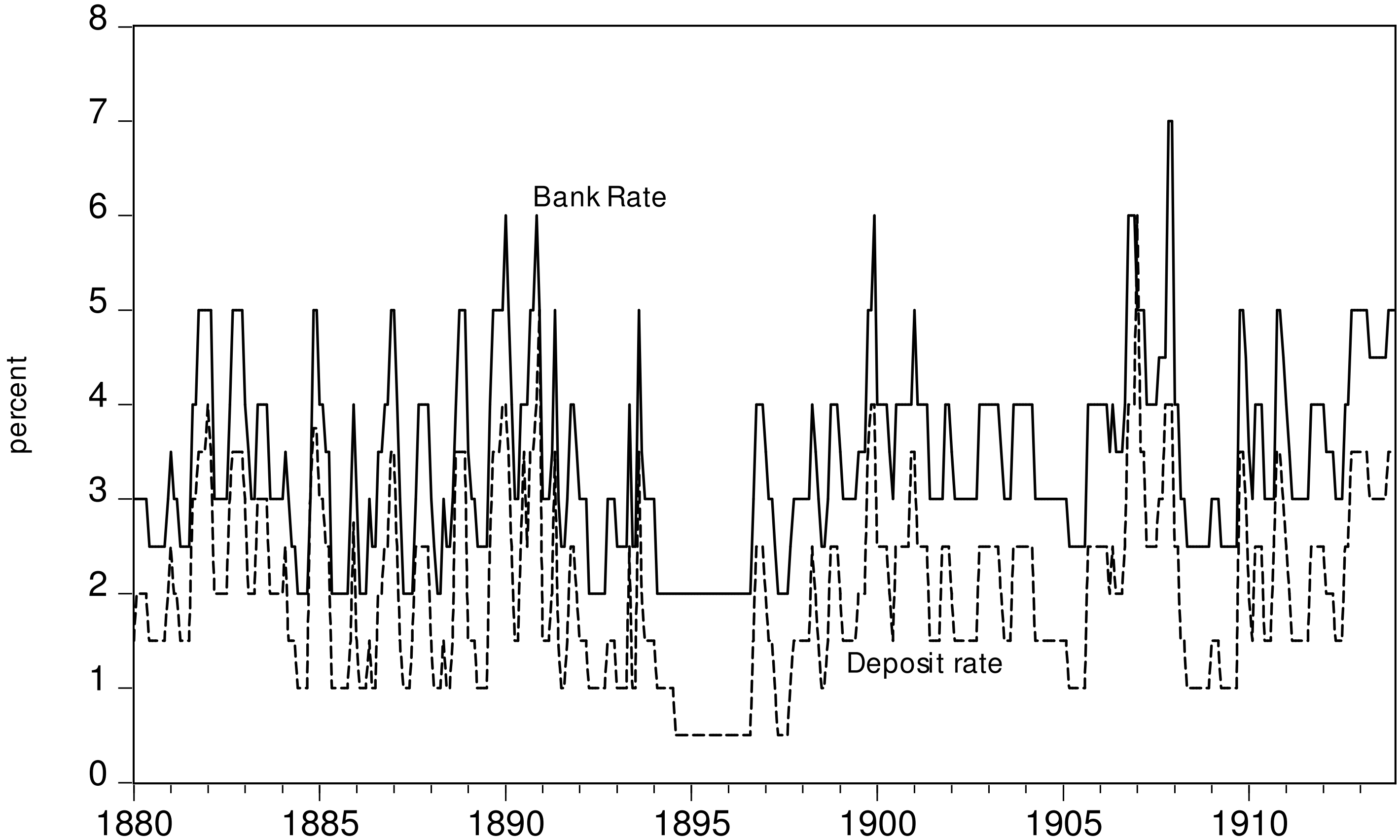

Figure 2 Bank Rate and prime three-month bill rate, January 1889-December 1910
Weekly, Fridays

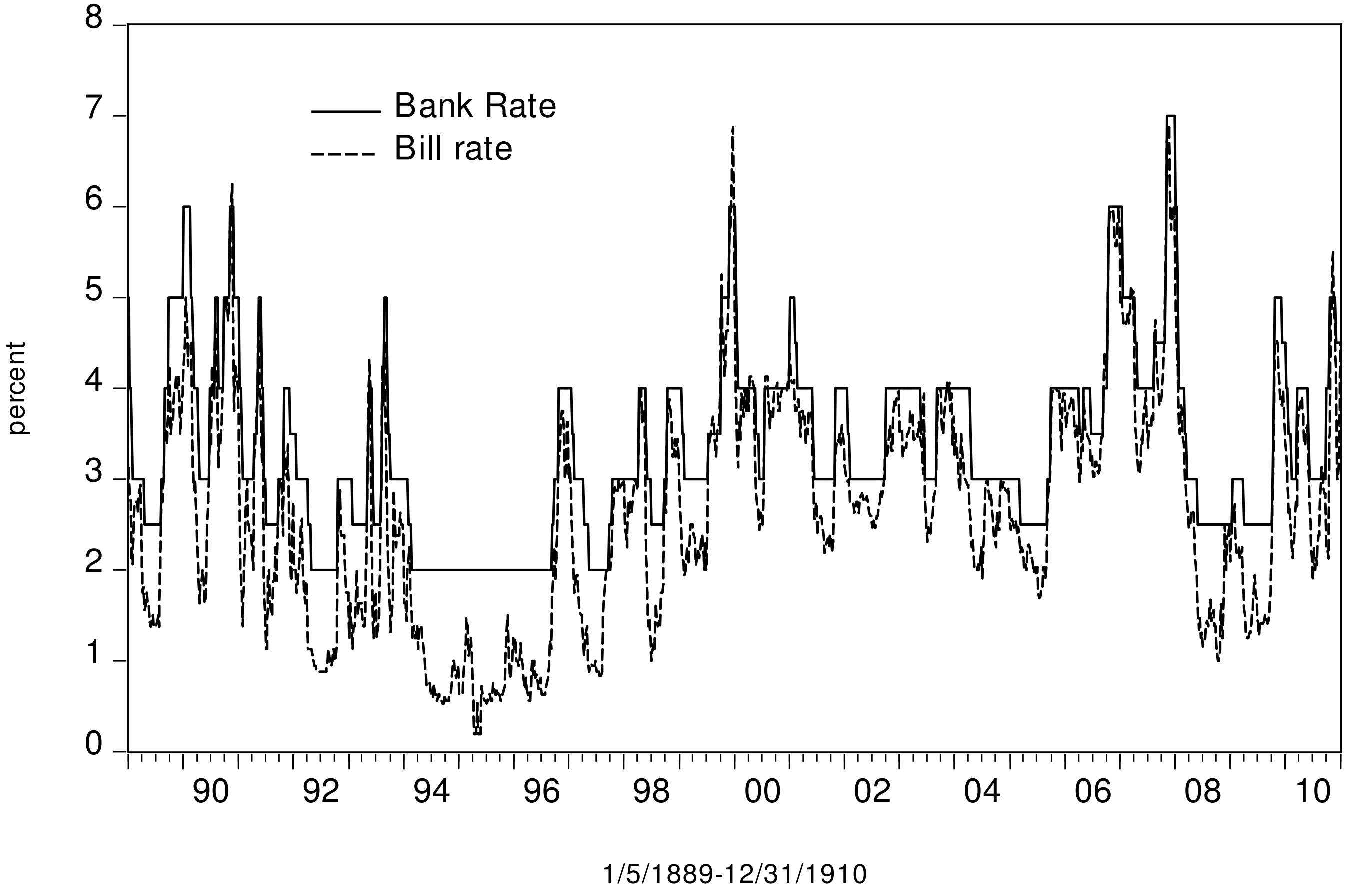

Figure 3 Bank Rate and call money rate, January 1889-December 1910
Weekly, Fridays

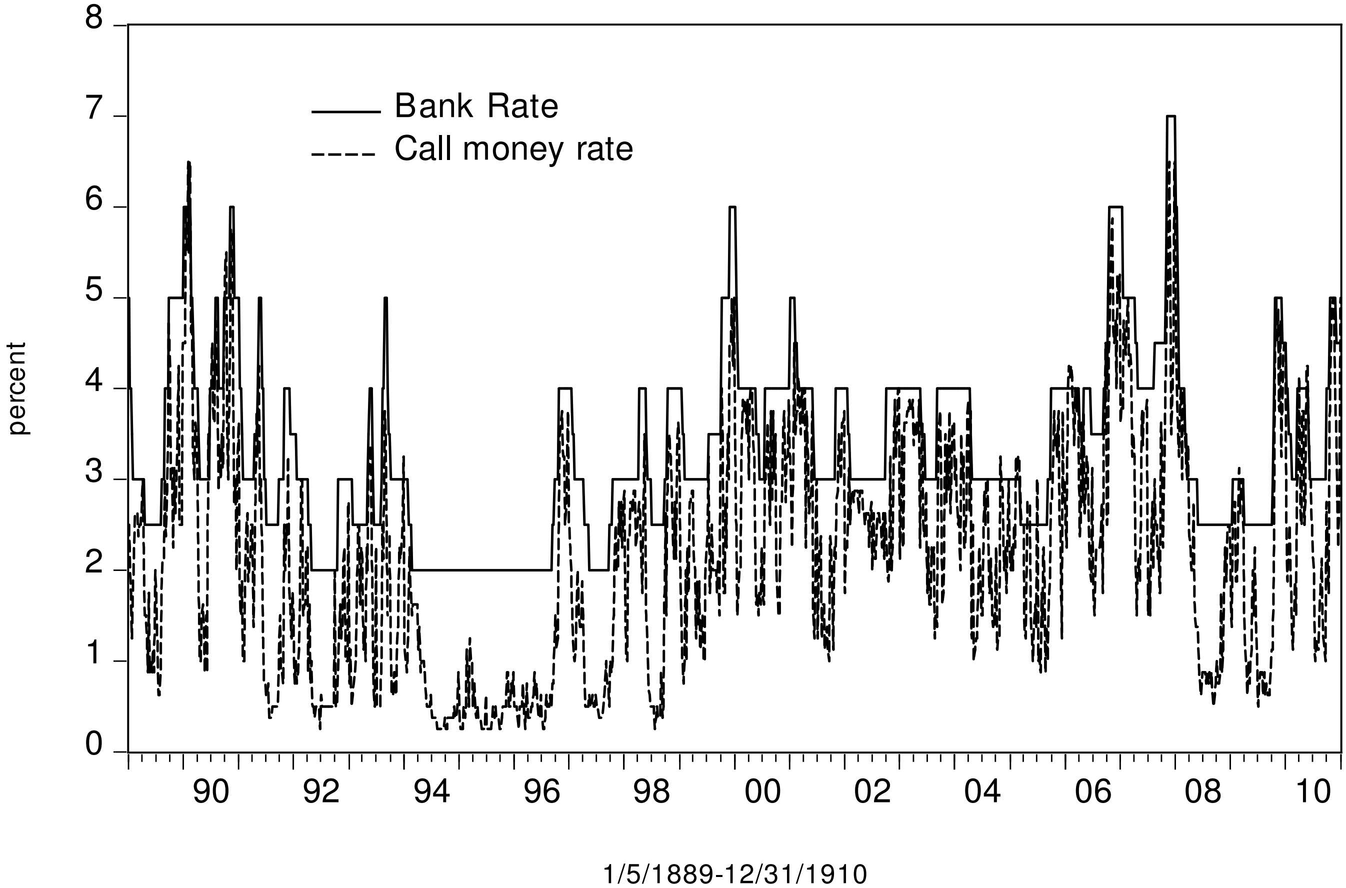

Figure 4 Bank Rate and Realized Bill-Call Money Spread, Monthly

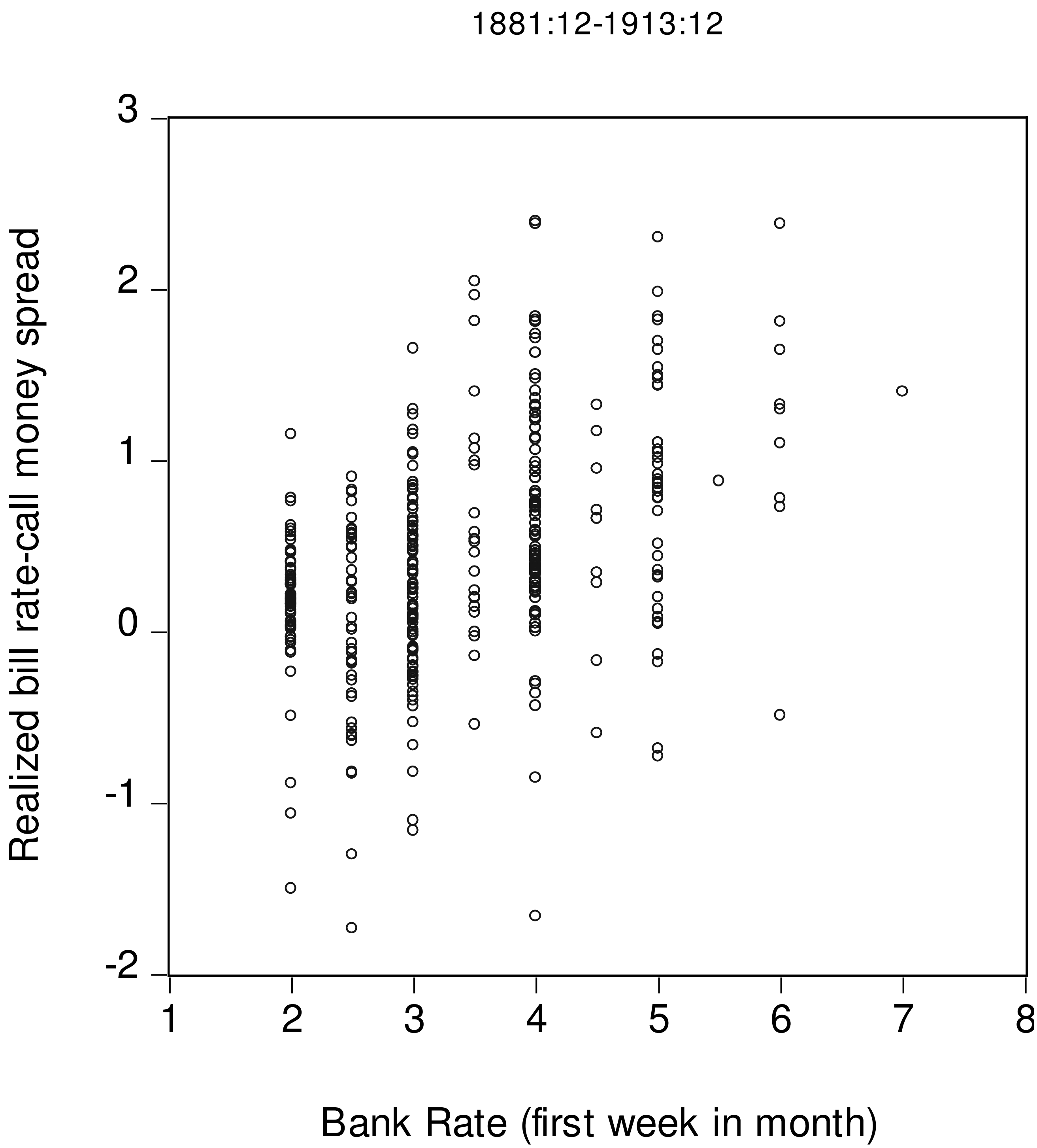

Table 1 Bank Rate and Realized Bill-Call Money Spread December 1881-December 1913
Coefficient
[Robust (White) SE]
p-value

Coeff. on	Entire period (1)	Entire period (2)	Exc. crises[1] (3)	Exc. crises[1] (4)	Exc. crises & $(i^{BR} - i^{B}) \leq 0.5\%$ (5)	Exc. crises & $(i^{BR} - i^{B}) \leq 0.5\%$ (6)
i^{BR}	0.353	0.323	0.366	0.332	0.281	0.198
	[0.037]	[0.076]	[0.041]	[0.080]	[0.054]	[0.121]
	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.10*
$\tilde{i}_{t-1}$		0.037		0.042		0.092
		[0.065]		[0.065]		[0.098]
		0.57		*0.51*		*0.35*
N. obs.	385	384	367	366	217	216
R^2	0.30	0.31	0.30	0.31	0.28	0.29

[1] 1890:7-1890:12, 1907:1-1907:12

Table 2 Call-money rate and reserve quantity 1881-1913, with call money rate on LHS

Coefficient
[Robust (White) SE]
p-value

A) June, December

	Entire period			Excluding crises[1]		
	(1)	(2)	(3)	(4)	(5)	(6)
i^B	0.977	0.881		0.932	0.895	
	[0.099]	[0.038]		[0.115]	[0.040]	
	0.00	*0.00*		*0.00*	*0.00*	
i^{BR}	-0.113		0.884	-0.047		0.964
	[0.121]		[0.080]	[0.144]		[0.072]
	0.35		*0.00*	*0.74*		*0.00*
Ln(R)	-1.910	-1.875	-1.512	-1.690	-1.672	-1.219
	[0.533]	[0.530]	[0.746]	[0.517]	[0.515]	[0.701]
	0.00	*0.00*	*0.05*	*0.00*	*0.00*	*0.09*
Ln(D)	0.829	0.838	1.020	0.554	0.568	0.864
	[0.411]	[0.414]	[0.588]	[0.412]	[0.417]	[0.549]
	0.05	*0.05*	*0.09*	*0.19*	*0.18*	*0.12*
N. obs.	66	66	66	63	63	63
R^2	0.94	0.94	0.87	0.94	0.94	0.88

[1] 1890 December, 1907 June and December

B) Monthly

	Entire period			Excluding crises[2]		
	(1)	(2)	(3)	(4)	(5)	(6)
i^B	0.779	0.885		0.747	0.894	
	[0.054]	[0.021]		[0.054]	[0.023]	
	0.00	*0.00*		*0.00*	*0.00*	
i^{BR}	0.137		0.985	0.194		1.013
	[0.070]		[0.033]	[0.071]		[0.032]
	0.05		*0.00*	*0.01*		*0.00*
Ln(R)	-1.211	-1.227	-1.312	-1.051	-1.085	-1.053]
	[0.218]	[0.222]	[0.259]	[0.217]	[0.225]	0.249]
	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
"Ln(D)"	0.654	0.659	0.796	0.866	0.845	1.041
	[0.185]	[0.183]	[0.239]	[0.181]	[0.183]	[0.241]
	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
N. obs.	388	388	388	370	370	370
R^2	0.91	0.91	0.85	0.91	0.91	0.86

[2] 1890:7-1890:12, 1907:1-1907:12

Table 3 Call-money rate and reserve quantity 1881-1913, with log reserves on LHS

Coefficient
[Robust (White) SE]
p-value

A) June, December	Entire period			Excluding crises[1]		
	(1)	(2)	(3)	(4)	(5)	(6)
i	-0.105	-0.103	-0.046	-0.108	-0.108	-0.045
	[0.029]	[0.029]	[0.023]	[0.033]	[0.033]	[0.027]
	0.00	*0.00*	*0.06*	*0.00*	*0.00*	*0.10*
i^B	0.121	0.095		0.128	0.101	
	[0.036]	[0.025]		[0.040]	[0.029]	
	0.00	*0.00*		*0.00*	*0.00*	
i^{BR}	-0.030		0.043	-0.034		0.044
	[0.027]		[0.020]	[0.033]		[0.027]
	0.28		*0.04*	*0.32*		*0.11*
Ln(D)	0.407	0.413	0.427	0.402	0.418	0.452
	[0.080]	[0.078]	[0.081]	[0.087]	[0.085]	[0.088]
	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
N. obs.	66	66	66	63	63	63
R^2	0.95	0.95	0.94	0.95	0.95	0.94

1 1890 December, 1907 June and December

B) Monthly	Entire period			Excluding crises[2]		
	(1)	(2)	(3)	(4)	(5)	(6)
i	-0.077	-0.076	-0.050	-0.072	-0.072	-0.044
	0.012	[0.012]	[0.010]	[0.013]	[0.013]	[0.011]
	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
i^B	0.053	0.054		0.054	0.054	
	[0.015]	[0.011]		[0.015]	[0.013]	
	0.00	*0.00*		*0.00*	*0.00*	
i^{BR}	0.002		0.032	0.000		0.030
	[0.013]		[0.011]	[0.014]		[0.012]
	0.91		*0.00*	*0.99*		*0.01*
"Ln(D)"	0.412	0.412	0.412	0.425	0.425	0.420
	[0.035]	[0.035]	[0.036]	[0.039]	[0.039]	[0.040]
	0.00	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*
N. obs.	388	388	388	370	370	370
R^2	0.93	0.93	0.93	0.93	0.93	0.93

2 1890:7-1890:12, 1907:1-1907:12