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An Early Experiment with "Permazero"

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Abstract: We investigate a monetary regime with persistent, near-zero policy interest rates ("permazero" in the terminology of Bullard 2015). This regime was implemented in 1683 by a prominent early central bank called the Bank of Amsterdam ("Bank"). The Bank fixed its policy rate at one-half percent and held it unchanged for more than a century. Maintaining the rate helped stabilize the value of Bank money. We employ archival data to reconstruct the Bank's activities during a portion of that interval (1736–91) for which data are most readily available. The data suggest that "permazero" worked well for long periods because the Bank counteracted market swings with quantitative operations. These same data show how fiscal exploitation denied the Bank sufficient resources to stabilize large shocks, with adverse results.

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1 Introduction

The art of monetary policy has changed since September 15, 2008. Post-crisis economic weakness has led many central banks to push their policy rates close to, and in some cases, a bit beyond the zero lower bound. The prospect of a binding (effective) lower bound has also led central banks to engage in extensive asset purchases, as an alternative channel for implementing monetary policy. The resulting policy environment has been characterized as unconventional and temporary, but as it persists, a scenario of continued low policy rates (dubbed "permazero" by Bullard 2015) has become empirically relevant for many economies.

What will be the long-term consequences of these policies? Central banks' post-2008 policies are often described as "unprecedented," but few monetary phenomena are truly lacking in historical precedents. The central bank analyzed below, in particular, offers an extended case study of a (near) permazero policy regime. The central bank in question, the Bank of Amsterdam (or "Bank"), set its annualized lending rate at one-half percent in 1683, and it maintained this rate up until its collapse in 1795. The Bank's commitment was unwavering because low rates helped anchor the value of Bank money, known as the *bank florin* or *bank guilder*. The Amsterdam money market responded favorably (Quinn and Roberds 2014), and Bank money became a dominant currency in Europe over much of this time. This was a policy with substantial economic consequences.

Our study uses data from the Bank's archives to reconstruct and analyze its balance sheet over 1736-1791, a sample that covers much of the low-policy-rate episode.[1] Analysis of these data shows that while the Bank did not vary its policy rate over this period, it was oftentimes far from passive. More specifically, Bank engaged in active management of its balance sheet in the form of frequent, large, and persistent rounds of open market interventions. The most extensive sequence of operations occurred over the 1750s, and these involved a monetary tightening on the order of 15 million bank florins or at least 6 percent of contemporary Dutch GDP, equivalent to about $1 trillion in modern U.S. terms. This is a modest scale of intervention by post-2008 standards, but close to what the capacity of the Bank allowed.

Our analysis also reveals how weaknesses in the Bank's policy framework were tested by financial markets. Fiscal exploitation of the Bank by its owner, the City of Amsterdam, introduced a fundamental asymmetry into the Bank's operations. Easing was always possible, but the Bank's tightening operations were limited by the availability of collateral to sell into the money market. Binding collateral constraints are manifested as sudden halts in the Bank's open market operations, and these are particularly evident over 1756-1763 (the Seven Years' War) and 1781-1790 (the Fourth Anglo-Dutch War and its aftermath). Both of these periods witnessed policy failures on the part of the Bank. The first period was characterized by an unstable value of the Bank's money, an ensuing credit bubble, and ultimately a Lehman-like money panic (De Jong-Keesing 1939, Schnabel and Shin 2004, Quinn and Roberds 2015). The second

[1] This sample period is dictated by data availability. For details see section 4 below.

period saw the Bank lapse into "policy insolvency" as a prelude to its collapse in 1795 (Van Dillen 1964b, Quinn and Roberds 2016).

This case study thus delivers a mixed message on the sustainability of low policy rates. On the positive side, skillful open market interventions by the Bank allowed it to maintain a near-zero policy rate over long periods without serious difficulty. Inflation remained stable, and bank credit provided at this rate demonstrably supported the Amsterdam financial markets. Sizeable amounts of such credit were dispensed by the Bank up until about 1780, and this credit matches or exceeds the Bank of England's discount credit over the first part of our sample.[2]

On the negative side, the Bank's policy approach was not resilient to large shocks. The reconstructed data show how the Bank tried to, but could not contain the pressures arising from wartime conditions experienced during the early 1760s and early 1780s. In the first instance, surging demand at the Bank's lending facility overwhelmed the Bank's ability to sterilize this credit creation. In the second instance, market participants abandoned the Bank's lending facility *en masse*, spawning another shock that the Bank could not offset, and ultimately rendering the Bank's policy rate irrelevant.

What implications does this eighteenth-century experience have for modern central banks? While acknowledging the differences between then and now, the key challenge faced by the Bank would seem relevant for modern central banks. This was the difficulty in maintaining both a low policy rate and a stable monetary value in the face of large, unforeseen shifts in market sentiment. The shortcomings of the Bank's approach to managing this challenge remained hidden for decades, only to be quickly revealed in the face of disruptive events.

The rest of this paper is organized as follows. Some relevant literature is surveyed in Section 2. Section 3 describes the structure of the Bank and explains how it implemented policy. Section 4 presents the data, and Section 5 presents some descriptive econometrics. Section 6 concludes.

2 Connections to the literature

The analysis below draws on a large literature on the Bank of Amsterdam, including the contemporary descriptions of Le Moine de L'Espine and Le Long (1763) and Adam Smith (1976 [1776]) and the historical accounts of Mees (1838), Van Dillen (1925, 1934, 1964a,b), Gillard (2004), and Dehing (2012). As in other work (Quinn and Roberds 2014, 2015, 2016) we extend this literature by reconstructing the Bank's balance sheet for the sample considered.

A number of similar studies have analyzed the activities of the Bank of England during the classical gold standard (from about 1870 to 1914). A pioneering analysis by Sayers (1936) showed that during this period, the Bank of England did not always rely on changes in its policy rate (the Bank rate), but instead used a variety of tactics to add or withdraw liquidity from the markets. One of these, open market sales and purchases of bullion or foreign coins,

[2] See Appendix F for a comparison.

matches a tactic employed by the Bank of Amsterdam some 150 years earlier. The full scope of the Bank of England's market activities has become apparent only recently, however, following quantitative reconstructions by Ugolini (2012, 2016).

The macro literature on extended low policy rates offers a range of predictions of their consequences. A highly cited theoretical analysis by Benhabib, Schmitt-Grohé, and Uribe (2001) (see Bullard (2010) for a discussion) suggests that an extended period at the lower bound can lead to unstable deflation and subpar growth. Bassetto and Phelan (2015) come to essentially the opposite conclusion, arguing that anchoring policy rates at zero can give rise to unstable expectations and inflationary breakouts. A third school of thought, known as "Neo-Fisherian," argues that fears about persistent low interest rates have been overblown, and that their main consequence would simply be to anchor inflation at low levels (see e.g., Cochrane 2016). The models employed in these papers do not directly map into the eighteenth-century Dutch economy due to structural differences discussed below. There are nonetheless some noteworthy resonances with the scenarios laid out in each of these papers.

No modern-style macroeconomic indicators exist for the eighteenth-century Netherlands, but available data suggest a stagnation or gradual decline in aggregate output. The historical literature (synthesized in De Vries and Van der Woude 1997, Chapter 13) attributes this to a heavy fiscal burden and loss of trade dominance rather than to monetary policy, however. Reconstructed price indices for this period indicate that prices were largely stable over this period, with annual inflation well below one percent (Van Zanden 2013). This price stability can be in part attributed to the Bank's adherence to a quasi-metallic standard, but also to a comprehensive 1694 coinage reform that reduced previous incentives for Dutch mints to debase the circulating coinage (Polak 1998). Finally, our breakdown of the Bank's balance sheet shows strong evidence of speculative attacks. However the form of these attacks more closely resembles attacks on a modern fixed-exchange-rate regime rather than the closed-economy scenarios laid out in Bassetto and Phelan (2015).

3 The Bank of Amsterdam

The Bank of Amsterdam (*Amsterdamsche Wisselbank*) was a prominent early public bank, founded in 1609 and liquidated in 1820. The Bank was chartered and owned by the City of Amsterdam, and its stated purpose was to provide a stable money for the settlement of bills of exchange drawn on Amsterdam merchants. The underlying environment in which the Bank operated was different from that of modern central banks. To understand the impact of the Bank's activities, a brief outline of this environment may be instructive.

Modern central banks operate in the context of deep and liquid markets for government debt instruments. In developed countries, these instruments are typically seen as the safest form of security, due to their low credit risk, superior liquidity, and suitability as collateral. A change in a central bank's policy rate operates classically (i.e., away from the lower bound) by changing the money price of government debt, which in practical terms is equivalent to a change in the price of a riskless claim on future consumption. This functionality was not available to the Bank of Amsterdam because the Dutch Republic (the seventeenth- and eighteenth-century Netherlands) had only fragmented and relatively illiquid markets for government debt (Gelderblom and Jonker 2011, Van Bochove 2013).

In a modern context, a central bank's policy rate may also impact the economy through its effect on the creation of private money, traditionally in the form of bank deposits, and more recently through repo and similar arrangements in the "shadow banking" sector (see e.g., Gorton, Lewellen, and Metrick 2012 or Singh 2016). The Dutch Republic had only very rudimentary and underdeveloped deposit banks (Jonker 1996), so the first channel was largely closed to the Bank of Amsterdam. The Bank did have a very active role in the provision of repo liquidity, however, as a provider of credit to contemporary analogues of "shadow banks."

In the absence of liquid government securities, the Bank's repo facility (described in detail below) utilized the most liquid form of available collateral, *trade coins*. These were high-denomination, high-metallic-content gold and silver coins produced in the Netherlands and elsewhere. Trade coins had special value in trade with markets outside the Netherlands (De Vries and Van der Woude 1997, 84), and they constituted the bulk of the Bank's backing assets. Trade coins also had a unique value within Amsterdam, due to their eligibility for a Bank facility where a Bank customer could, in effect, borrow against trade coins to obtain credit on their Bank account. These accounts are the money the Bank lent at a low rate.

Bank accounts were valuable because they were the sole legal means to discharge bills of exchange payable in Amsterdam. As Adam Smith noted, "Every Merchant, in consequence of this regulation, was obliged to keep an account with the bank in order to pay his foreign bills of exchange, which necessarily occasioned a certain demand for bank money (1976 [1776]: 481)." Bills, in turn, were central to the money market because merchant bankers 1) lent by purchasing bills and 2) funded this lending by accepting bills instead of deposits. This "matched-book" approach to leverage created an early example of "shadow banking." There were effectively no capital controls, and local merchants and their foreign counterparties could easily move funds across national borders, or borrow and lend short-term, by drawing bills on counterparties abroad or accepting bills from these counterparties.

For much of the period we study, Amsterdam was home to the deepest bill market in Europe (Gillard 2004, Flandreau et al. 2009, Carlos and Neal 2011, Dehing 2012). Payments activity through the Bank was correspondingly intense. Turnover in Bank accounts was about 388 million florins in the early 1760s (Dehing 2012, 82 and 140), equal in value to almost 4,000 tons of silver, or 1.5 to 2 times annual Dutch GDP. Since bills could circulate via endorsement, and a few bills settled outside the Bank, the true amount of liquidity created in the Amsterdam bill market was undoubtedly higher than these figures suggest. As a standard of comparison, an analogous ratio for the Federal Reserve (annual value of Fedwire payments/ U.S. GDP) comes in at 2.5 at the peak of the Bretton-Woods era (1955 figures from Bank for International Settlements 1980, 265).

3.1 Basic structure of the Bank

To provide "a stable money" during the eighteenth century meant only one thing: that the money in question could be readily converted, at a predictable price, into coin with a high precious metal content. This fact of life was always the focus of the Bank's policies. Following a 1683 policy change, however, the Bank of Amsterdam's money evolved into a de facto fiat money, in the sense that it carried no inherent right of redemption: the metallic value of the bank florin was what the market determined it to be (see e.g., Van Dillen 1934, 1964a; Dehing 2012; Quinn and Roberds 2014). As a publicly owned manager of a fiat money, the Bank was a true "central bank." A stylized balance sheet for the Bank is shown in Table 1.

Table 1: Balance sheet of the Bank of Amsterdam (18th century)

Assets	*Liabilities + equity*
Coins under receipt (eligible for repurchase) E Unencumbered coins (not eligible for repurchase) U Loans L	Account balances M Equity ε

Inspection of the table reveals some distinctions between the structure of the Bank and that of modern central banks. The monetary liabilities (denoted M) of the Bank existed only as balances in Bank accounts, since the Bank never issued circulating currency. These accounts correspond to "reserve accounts" at modern central banks; every merchant bank and most large merchants in Amsterdam had such an account.[3] On the asset side, the bulk of the Bank's portfolio consisted of silver (and to a lesser extent, gold) coin rather than government securities favored by today's central banks. Following the Bank's own accounting system, we divide the Bank's holdings of coins into two categories, E and U, according to whether they were subject to options known as *receipts*.

3.1.1 The receipt window

Modern central banks commonly interact with financial markets via repurchase (repo) transactions. The Bank of Amsterdam employed a functionally similar interaction with the markets, through the issue of receipts. An account holder at the Bank who wanted to convert trade coin to bank money could sell the coin to the Bank at a posted official price, receiving in return 1) credit to his Bank account and 2) a receipt for the coin sold. A receipt was, in modern terminology, an American call option on the type of coin sold (and no other coin) with an expiration date of six months after the sale, and a strike price slightly above the original sale price.

[3] In principle anyone, not just banks, could open an account at the Bank. In practice, accounts were used only by those parties likely to deal with bills of exchange: the very wealthy and public institutions. At its mid-eighteenth-century peak, the Bank maintained about 3,000 accounts as compared to Amsterdam's population of 200,000 (Dehing and 't Hart 1997).

Take for example a transaction: Jan Albert Vos sold 800 silver coins called *ryxdaalders* to the Bank, and this increased the Bank's account liabilities by 1,920 florins with a corresponding increase in assets. The transaction used the Bank's official value of the coins purchased; see Table 2.A below.[4]

Table 2: Three ways to create Bank money with balance sheet effects

A. Sale of trade coins to the Bank February 25, 1737	
Assets	*Liabilities + equity*
+ 1,920 florins in encumbered *ryxdaalder* coins (E)	+ 1,920 florins in balances (M)
B. Purchase of one-guilder coins by the Bank March 15, 1737	
Assets	*Liabilities + Equity*
+ 24,709.875 florins in unencumbered *gulden* coins (U)	+ 25,000 florins in balances (M) - 290.125 florins in equity (ε)*
C. Loan to the Dutch East India Company March 13, 1737	
Assets	*Liabilities*
+ 100,000 florins in loan principal (L)	+ 100,000 florins in balances (M)

* A loss created by adjusting the asset (25,945.375 *gulden* coins) from the purchase agio of 3 15/16 percent to the record keeping agio of 5 percent. At sale, the reverse adjustment creates a profit.

Sources: A. Amsterdam Municipal Archives 5077/297 folio 1308 and AMA 5077/1378 folio 47. B. AMA 5077/1378 folio 44. C. AMA 5077/297 folio 1503.

Coins held in the Bank's vault that had outstanding receipts (denoted *E*) were in effect "encumbered," i.e., subject to exercise of the call option embedded in the receipt. For convenience we will sometimes refer to sales of trade coins against receipts as "deposits." These were not however deposits in the modern sense of a generalized demandable debt claim against the Bank. Instead, such sales generated a negotiable claim against only a specific type of collateral, i.e., a receipt.

For silver trade coins that constituted the bulk of the Bank's receipt business, the "strike price" of a receipt was always one-fourth percent higher than the sale price. For a few favored domestic silver coins, this margin fell to one-eighth percent, and it rose to one-half percent for gold coins. In the rare instances of rate adjustment, the Bank standardized rates to one-

[4] *Ryxdaalders* (a.k.a. rixdollars) were silver Dutch coins worth 2.4 bank florins each. The transaction involved four sacks of 200 coins each.

fourth percent.[5] Receipts could be rolled over at the same cost as for redemption, and were fully negotiable as bearer instruments.[6]

The great majority of the time, the call option inherent in a receipt was "in the money," i.e., the price for repurchasing the coin listed on the receipt was below its market value, so that the receipt was eventually redeemed. The function of a receipt was thus much like a modern central bank (term) repo, providing liquidity to the money market against liquid collateral at a policy interest rate. From the beginning of the receipt system in 1683, the Bank's implied policy interest rate was simply the redemption fee of *one-fourth percent per six months, or about one-half percent annualized*. Such a low rate was feasible because inflation during this period was effectively zero, and the quality of the collateral involved (trade coins) was such that the issue of receipts entailed little risk to the Bank.

There are instances in our dataset where market participants allowed these receipts to expire. For example, a few times the Bank reduced the value of domestic gold coins, and their receipts went out of the money. In such instances, the trade coins in question lost their encumbrance and became owned by the Bank. Since a receipt was just an option to exchange Bank money for coin, expiration of a receipt had no effect on the stock of Bank money.

Despite the clear parallels, there is also an important difference between the receipt system and modern central bank repos. The policy interest rate inherent in the receipt system was an administered rate rather than a target for market rates, as is preferred by many central banks today. Also, the rate applied to a standing facility whereby the Bank offered as much credit as the market demanded. The quantity of credit generated through this facility was thus not under direct control of the Bank. This did not mean that the Bank was indifferent to fluctuations in its money stock, as will be shown below.

3.1.2 Operations in unencumbered coin

An alternative way for Amsterdam merchants to acquire Bank funds was to purchase such funds from people with accounts at the Bank. This was often done through brokers who were active in a secondary market that took place every morning in front of the Bank. In this market, circulating coins could be converted to bank florins and vice versa, at bid-ask spreads of one-eighth percent or lower.[7] Circulating money was denominated in a separate unit of account known as the *current florin* or *current guilder*. The market price of bank money was recorded as an *agio* or premium of bank florins over current florins, i.e., a price of 1.05 current florins per bank florin was recorded as an agio of five percent. As a shorthand, we will use

[5] In 1765, the rate on three-guilder coins increased from one-eighth to one-fourth percent per. See Amsterdam Municipal Archives, 5077/1392, folio 92. In 1776, the rate on all gold coins decreased from one-half to one-fourth percent. See Amsterdam Municipal Archives, 5077/1397, folios 58-9, 66-7, 121-132.

[6] Contemporary descriptions of the Amsterdam money market, such as those found in Le Moine de L'Espine and Le Long (1763) and in Smith (1976 [1776]: 485) describe an active secondary market in receipts. Unfortunately very few records of such transactions survive.

[7] This market was also used by merchants without a Bank account to transact in bank florins through specialized brokers.

“florin” for bank unit of account and “guilder” for current unit of account. The notation a_M will be used to denote the market agio.

Figure 1 plots monthly values of a_M from December 1735 to January 1792. The agio stays between four and five percent for most of the sample except during the Seven Years’ War (1756-1763), and during the period of the Bank’s decline from the Fourth Anglo-Dutch War (1780-1784) onward.

<Figure 1 here.>

The Bank routinely intervened in the secondary market for bank florins, buying and selling large quantities of coin at the going market price (rather than at an official price as with the receipt window), in the same way as modern central banks buy and sell securities in open market transactions. No receipts were granted for these “outright” transactions, which during our era of interest were often conducted in small-denomination coins with one-guilder face value called *gulden*. These were not considered trade coins and were ineligible for the receipt window. The Bank’s purchase operations, together with trade coins whose receipts had expired, gave rise to a stock of unencumbered coin U in the Bank’s vault.

For an example, we return to 1737. The Bank purchased 25,945.375 current guilders (in the form of *gulden* coins) from Arnoud Borchers at an agio of 3 15/16 percent. Borchers got 25,000 bank florins with a corresponding increase in coin held by the Bank (see Table 2.B). To simplify accounting, purchased coin was carried on the Bank’s books at a fixed agio, usually five percent. Any difference between this value and the market value of coins bought or sold was resolved through a one-time adjustment to the Bank’s equity. Purchased coins were not “marked to market.” Coin acquired by the Bank in this fashion was not subject to receipt claims and could be readily sold back into the market.

3.1.3 Loans

The Bank’s charter excluded it from making loans—other than granting credit through the receipt window, which was not considered lending. In practice, however, the Bank routinely engaged in lending activity throughout its existence. The great bulk of the Bank’s loans were made to two privileged borrowers, the Dutch East India Company (“Company”, also known by its Dutch initials VOC) and the City of Amsterdam (“City”). The differences in how the Bank accounted for the two types of loans is indicative of the political economy within which the Bank operated.

The Company frequently borrowed balances on short-term from the Bank against unsecured notes known as anticipations, which were to be repaid by the sale of goods in transit from Asia to the Netherlands. These and other loans to the Company show up in the Bank’s balance sheet as increases in loan assets (denoted L) and increases in account liabilities M. For example, a loan of 100,000 florins to the Company increased the stock of Bank ledger money by the same amount (Table 2.C). Such short-term borrowing allowed the Company to outfit one year's trading fleet and pay out dividends to its stockholders, while awaiting the return of a previous year's fleet. Interest on such loans was an important source of income to the Bank (Uittenbogaard 2009), and most of these loans appear to have been granted automatically, on an as-needed basis.

Since the City owned the Bank, its status as a borrower was different from the Company's. Until the 1780s, loans extended to the City carried no interest, were operationalized through the removal of unencumbered coin *U* from the Bank's vault. These had no direct effect on the amount of bank florins outstanding. The City attended to these "loans" when and how (write-down or repay) it wanted, so they functioned as adjustments to the Bank's equity (denoted ε). This also occurred when the City took the Bank's residual profits as a seigniorage dividend. If such loans are treated more realistically as takings (and recapitalizations when repaid), then the Bank had negative equity for most of the sample studied.[8]

City loans enter this paper's sample of account transactions only when the City began to borrow bank balances in 1782. The City directed most of these new bank florins to a new municipal lending agency (*Stadsbeleeningkamer* or "municipal loan chamber") that the City used to disperse loans to individuals.[9] The loan chamber did reliably repay the bank with 2 percent interest, but the chamber continuously re-borrowed to do so. It is unclear whether the Bank was even permitted to ration the supply of credit to the chamber.

3.2 Mechanics of policy implementation

Our analysis uses the structure shown in Table 1 to decompose Bank money *M* into three categories, reflecting the mix of "backing assets." It should be emphasized that this decomposition is a convenient conceptual device and that it never appears in the Bank's archives. The decomposition can be written as

$$M = M_E + M_U + M_L \quad ,$$

where

$$M_E \equiv E \quad ,$$

[8] Negative equity is not unheard of for central banks, which as a rule tend to be thinly capitalized (see Archer and Moser-Boehm 2013 for a survey of central bank accounting). A more valid indicator of a central bank's health is usually given by its *net worth*, which is its equity augmented by the "franchise value" of discounted future seigniorage earnings (see e.g. Fry 1993, Stella 1997, 2005, Stella and Lönnberg 2008, Del Negro and Sims 2015). The net worth of the Bank of Amsterdam was positive until about 1780.

[9] The City also experimented with repaying loans to the city treasury with interest. In 1783, the City repaid with interest 800,000 of a 1.4 million-florin line of credit. Then the City gave up the effort, and its remaining 600,000-florin loan balance became permanently non-performing.

$$M_U \equiv U \quad ,$$

$$M_L \equiv L - \varepsilon \quad .$$

In words, the first component M_E represents the quantity of Bank money backed by coins under receipt, which is identically equal to the value of encumbered coin E in the Bank's vault. This was the amount of money that could be instantaneously converted to trade coin through the exercise of receipts. The right to redemption was, however, bound to the receipts rather than the money itself. The second component M_U is identically equal to unencumbered coin U held by the Bank. The third and final component M_L is identically equal to lending by the Bank, including Company loans recorded as L and the City's various takings of Bank equity, which show up as $-\varepsilon$.[10]

3.2.1 Policy operations

The discretionary policy operations of the Bank show up as changes to M_U, reflecting sales and purchases of its unencumbered metallic assets in the daily, secondary market for bank money. The Bank's charter contained no guidance as to how such transactions should be carried out, and indeed it is not clear that the Bank ever had formal legal authority to conduct its open market operations. The extent of these transactions, like the other details of the Bank's balance sheet, was never public information. Given their often massive size, however, the existence of these operations must have been known to market participants and at least informally sanctioned by the City.

The Bank could use these transactions to offset fluctuations in Bank money arising from the receipt window and from credit extended to the City and the Company. An upsurge in receipts, for example, could be offset with a sale of *gulden* coins. Under this scenario, participants in the Amsterdam money market would then have temporarily swapped internationally liquid collateral (trade coins) for domestically liquid collateral (*gulden* coins). Similar situations occurred when the Bank offset inflows of silver coins at the receipt window with sales of gold coins. These scenarios may be compared to situations, say, where a modern central bank offsets liquidity created via repos in one class of assets by outright sales of another.

Benchmark results such as Wallace's (1981) Modigliani-Miller theorem raise the question of why the Bank's open market operations might have mattered for market allocations. One answer to this question may be found in the different liquidity values associated with various types of coin. Gold and large-denomination silver coins were preferred in large-value transactions in distant markets, while the small-denomination coins such as the one-guilder *gulden*

[10] The monetary components M_E and M_U are nonnegative by construction. For M_L, however, low levels of lending can sometimes lead to negative values. In our sample, such values are sufficiently small in absolute value (<2 percent of the money stock) and infrequent (7 months of our sample) that we chose to treat them as effectively equal to zero, rather than modify our accounting framework to correct for their occurrence.

coins were more useful in local, everyday commerce. Changes in market prices of gold and silver would also have impacted market preferences. Directly converting one coin to another would have entailed mint charges of around one percent in each direction (Polak 1998, 169-179) as well other transaction costs. Use of the receipt window and the Bank's compensating operations allowed the market ready access to its preferred form of collateral.

At a somewhat deeper level, the Bank's open market interventions mattered because they shifted the degree and nature of its metallic backing. Open market purchases temporarily increased the quantity of unencumbered coin held by the Bank, but such coin then became subject to seizure by the City. Recent theoretical findings (Sims and Del Negro 2015, Benigno and Nisticò 2015) suggest that these shifts might have been less consequential if the Bank had enjoyed airtight fiscal guarantees from the City. In practice, however, the fiscal relationship between Bank and the City was highly exploitative and the extent of the Bank's fiscal backing was ambiguous. Eventually, at the very end of our sample in 1791, the City was forced to inject capital into the distressed Bank (Quinn and Roberds 2016). By this point, however, the Bank's international reputation had been largely destroyed.

3.3 Policy constraints

The Bank's first and foremost policy goal was to maintain a stable value for its money, and the universally acknowledged barometer of the bank florin's monetary value was the market agio. There was, however, no publicly announced "target band" for the market agio, nor is there any discussion of a band in the Bank's archives until 1782 (Van Dillen 1925, 433-434). Policies adopted by the Bank appear to have kept the market agio within its implicit band of 4 to 5 percent over the stable periods of our sample. Since the metallic content of Dutch silver coinage was largely constant during this time, a stable agio also implied a stable metallic value for the bank florin.[11]

The target level derived from the coinage laws of the Dutch Republic. Each domestic trade coin *C* had an implicit agio a_C, defined by

$$a_C = 100 \times \left(\left(\frac{\text{legal value of coin } C \text{ in current guilders}}{\text{legal value of coin } C \text{ in bank florins}} \right) - 1 \right)$$

For example, ordinances declared that the *ryxdaalder* coins deposited by Mr. Vos in Table 2.A to be worth 2.5 current guilders each outside the Bank, versus 2.4 florins within the bank.[12] Acquiring *ryxdaalder* coins and then depositing them created an implicit agio of $a_{rvxdaalder} = 100\left(\left(2.5/2.4\right)-1\right) = 4.167\%$. Each trade coin had a slightly different implicit agio

[11] A target band of four to five percent "in late years," supported by open market operations, is cited by Adam Smith (1976 [1776], 486). Smith's information on the activities of the Bank came from Henry Hope, a principal in the largest merchant bank in Amsterdam.

[12] A coin's market price could be even higher if the value of the coins' silver content was sufficiently above the ordinance value.

because bank florin and current guilder values varied slightly (see Polak 1998). These implicit agios applied to the first "leg" of the receipt agreement and set the "anchor" in the 4 to 5 percent range.

To repurchase in the second "leg," customers also had to pay the one-fourth percent fee, so the implicit agio for each coin leaving the Bank was greater than when entering by the amount of the fee. The low-fee policy made that the implicit agio for outgoing coins only one-fourth percentile greater than incoming coins. Before the 1683, Bank fees had been higher, and consequently, the anchor range had been greater (Quinn and Roberds 2014, 3). The consistently low policy rate translated into the consistently narrow anchor range exhibited in Figure 1.

To illustrate the connections creating is anchoring effect, Table 3 summarizes the relationship between balances in the Bank and two forms of money outside the Bank: *gulden* coins and trade coins. The latter two monies each have their own channels to Bank money, i.e., the receipt windows (for trade coins) giving rise to M_E and the agio spot market (for *gulden*) giving rise to M_U. To connect the monies outside the bank, the table adds the exchange of trade coins for current guilders. People could exchange current guilders for trade coins to realize an implicit agio (through the receipt window) and create a specie-flow process. For example, a high market agio relative to a coin's implicit agio encourages sales of trade coins (discourages receipt redemptions) that increase the stock of bank florins and push down the market agio.[13] As with other specie-flow examples such as the classical gold standard, these incentives can prove weaker than the other reasons people exchange money.

Table 3. Exchange of different monies within Amsterdam

Monetary instrument (unit of account)	Trade coins (florins/guilders)	*Gulden* coins (current guilders)
Bank balances (bank florins)	Receipt window *(bank florins/trade coin)*	Open market operations *(current guilders/bank florin)*
Gulden coins (current guilders)	Money changers *(current guilders/trade coin)*	X

The structure of receipts complicated the anchoring process. A market agio below the range of the implicit agios encouraged receipt redemptions, but one had to have a receipt to take advantage. Receipts could be purchased from other people, so Dehing (2012, 124-6) argues that receipt prices had an inverse relationship to the market agio. While there is insufficient data to confirm the strength of this relationship, paying more to acquire a receipt reduces the gains from using receipts. Similarly, the ability to sell a valuable receipt undermines the disincentives to sell trade coins to the Bank when the agio is low. In contrast, receipts have

[13] There is a resonance here with a famous proposal by Merton Miller (1998), that Hong Kong stabilize the value of its currency through the issue of securities with embedded put options.

little value when the agio is above the target range, so incentives are less affected. In the extreme, receipts could have so little value that people do not pay to roll them over. As a result, the anchoring properties are stronger for agios above the target range than below.

The connections in Table 3 also mean that Bank operations could alter receipt window behavior. Open market operations act directly on the level of bank florins to pressure the market agio a_M, but changing a_M also alters its relationship with each trade coin's implicit agio a_C. A stronger (weaker) a_M increases (decreases) incentives to use the alternative channel of the receipt window to acquire bank money. Such feedback mitigates the response to open market operations.

3.3.1 Vulnerabilities

The criticality of an exchange rate (the market agio) in the Bank's policy framework invites a comparison to more recent monetary institutions, e.g., central banks that operated under the classical gold standard, or modern central banks operating under an exchange rate peg. Such comparisons have some validity, since eighteenth-century Amsterdam had essentially no capital controls, and the Bank was, like these institutions, fully subject to the stresses of the Mundell-Fleming "trilemma." One key factor that distinguishes the Bank of Amsterdam from these later examples is the Bank's approach to managing the trilemma, which was wholly restricted to quantitative operations. A modern central bank would be reluctant to adopt such an approach, particularly in light of unfavorable twentieth-century experiences with fixed exchange-rate regimes (see e.g., Bordo and James 2014). The Bank of Amsterdam, by contrast, seems to have been largely unconcerned until close to the end of its existence.

One reason for this lack of concern may have been incomplete understanding. The idea that a central bank should manipulate its policy interest rate in order to manage its exchange rate was not well developed at the time: the Bank of England, to cite another contemporary example, moved its policy rate (the Bank Rate) only a few times in the eighteenth century, and then only within a relative narrow range of 4-6 percent (Homer and Sylla 2011, Table 14). A second reason for the Bank's relative indifference to the trilemma may have been the informality of its policy target, which meant that the Bank could tolerate some volatility in the agio during periods of stress. This accords with modern central banking experience, in the sense that central banks that enforce looser exchange rate pegs tend to enjoy more monetary autonomy (Klein and Shambaugh 2015). Finally, contemporary descriptions of the Bank express faith in the receipt window as an anchoring mechanism, with any deviations from the official value of the agio seen as being subject to corrective market forces.

In our sample, the receipt window proved vulnerable to two modes of speculative attack. In the first type of attack, pessimistic receipt holders (including people who had purchased receipts on the open market) could simply redeem their receipts *en masse*. This occurred over 1781-1783 when people apparently feared the Bank might renege on receipt obligations. The Bank could (and did) attempt to sterilize the resulting monetary contraction through open market purchases, but doing so drastically shifted the composition of the Bank's metallic backing. Restoring the credibility of the restructured Bank then required a sizeable capital injection, which the City was reluctant to provide.

The data suggest that the Bank was subject to a second and subtler type of speculative attack during the Seven Years' War (1756-1763). At that time, market participants apparently retained faith that the Bank would honor receipt obligations, but participants had a negative outlook for the bank florin. They found it attractive to sell trade coins to the Bank through the receipt window. The proceeds could then be used to purchase foreign currency forward (bills drawn on foreign markets), as a hedge against florin depreciation. The receipts granted by the Bank would then have functioned as put options on the domestic value of the bank florin, ensuring that the receipt window remained popular even though the market agio was low (see Appendix C for some illustrative calculations). The resulting inflow of trade coin through the receipt window increased the stock of Bank money, putting further negative pressure on the bank florin and reinforcing negative market sentiment. Volatility of the agio also increased at this time (see Appendix B), which would have worked to increase receipts' value. To defend against the weakening of the florin in foreign and domestic markets, the Bank lacked the option of raising its policy rate. It could sell unencumbered metal into the market, but such activity could not always be sustained.[14]

Other factors impacting Bank policy were the price and quality of coins. In the seventeenth century, debasement of silver coins created dramatic challenges for the Bank (Quinn and Roberds 2007). In the eighteenth century, the quality of Dutch coin had become very stable, and the silver *gulden* was the domestic numeraire. In contrast, Dutch gold coins circulated at values that varied with the price of gold, and this price could vary sharply over the short term. These forces brought waves of gold into the Bank's window. In the extreme, the receipts for gold coins went "out of the money," and people abandoned their right to withdrawal. Under this scenario, significant amounts of gold fell into the outright ownership of the Bank, creating substantial stocks of unencumbered gold coin for the Bank to manage.[15]

4 Data

To examine the history of the Bank's market, its policy operations, and their interactions, we reconstructed each transaction that altered the amount of bank florins from January 1736 through December 1791. Records of these transactions exist because the Bank was owned by the city of Amsterdam, and the city maintains the ledgers in its municipal archives. We begin in 1736 when the Bank simplified its internal accounting processes, and end with the last year

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[14] The pessimists' fears were confirmed in August 1763, when the market agio briefly fell below zero following the failure of a prominent merchant bank (De Jong Keesing 1939, 165). The Bank responded by declaring silver bullion eligible for the receipt window (at a steep haircut). This response shored up the liquidity of market participants, broke the negative psychology of the panic, and allowed the agio to recover to its normal range (Quinn and Roberds 2015).

[15] Appendix D examines the impact of bimetallic ratios on the Bank's balance sheet over our sample.

with complete records. The Bank maintained meticulous double-entry records, so the Bank's master account contains the relevant transactions, a total of 73,479 entries.[16]

As a concession to practicality, these entries were aggregated to monthly (month end) data. Figure 2 gives the total level of account balances for 672 months. In terms of the balance sheet (Table 1), this is the level of the Bank's total monetary liabilities *M*, and that level is stable over long periods of time. The series stays between 15 and 25 million florins for 88 percent of the months. The only major deviation is the peak surrounding the crisis of 1763. This stability is in no small part explained by active policy on the part of the Bank, but to see that we must disaggregate each transaction's purpose.

<Figure 2 here.>

The Bank's account ledgers do not detail the whether a change in Bank balances stems from a deposit/withdrawal (i.e., a change in encumbered coin *E*), a loan/repayment (change in *L*), a purchase/sale (change in *U*), or an adjustment in equity ε such as from fees and interest payments. That information mostly resides in another set of books that records flows of metal and related fees.[17] Referring again to Bank's balance sheet in Table 1, these "cash books" track changes in coins on the asset side of the balance sheet. Through the arduous reconciliation of the two sets, we identify an offsetting change in the balance sheet for each change in monetary liabilities.[18] Using this information, we can separate monetary liabilities *M* by the three other constituent parts of the balance sheet suggested in Section 3 through the identity $M=M_E+M_U+M_L$. Again, these are liabilities backed by coins encumbered by receipts M_E, liabilities backed by unencumbered metal M_U, and liabilities backed by loans less equity M_L.

Figure 3 plots this deconstruction. It reveals considerable movement in the three monetary components. The most striking result is the dramatic variation in the level of money backed by coins under receipt M_E. For example, the 1764 peak in total monetary liabilities of 32 million is almost completely backed by receipts. At the other extreme, M_E is only 375,000 in 1783. To sharpen this point, Figure 4 converts the three component series into shares of the total monetary stock *M*. Our period opens with receipts accounting for two-thirds of all bank

[16] The master account was called the *specie kamer* ("coin room"), and we photographed those account folios within dedicated ledgers (AMA 5077/1338-1349) when available, or else within regular ledgers or *grootboeken* of the Bank (AMA 5077/192-609). This master account was a forerunner of the System Open Market Account at the Federal Reserve and analogous accounts at other modern central banks. A portion of this dataset (1781-1792) was employed in an earlier paper (Quinn and Roberds 2016).

[17] These ledgers are called *kasboeken* ("cash books": AMA 5077/ 1355-1387). They do not detail transactions unrelated to metal such as loans and transfer fees.

[18] Some years (1747-1760) lack a cash book, so we deploy filters using regularities identified from the years that we do have. Appendix A details how we did this and our robustness checks. Other years (1738, 1742, 1778, and 1780) lack complete account ledgers, so we derive account transactions from cash books. Fortunately, all years in our sample have either an account ledger or a cash book, so it is possible to construct a continuous and generally accurate record of the Bank's operations. An earlier paper (Quinn and Roberds 2014) decomposes the Bank's seventeenth-century ledgers using a "Furfine" algorithm, which necessarily results in misclassification of some transactions. The techniques used here are more accurate in general and almost error-free for years in which complete records exist.

florins. Eight years later, that is down to one-fifth. At its peak, receipts account for 97 percent of all bank money. At its nadir, 2 percent. As set out in Section 3, the Bank may have had an agio anchor between 4 and 5 percent, and specie-flow mechanisms may have been at work, but other factors must have been present in order to account for this degree of volatility.

<Figures 3 and 4 here.>

To maintain the stability of its monetary total, the Bank appears to adjust what it can control, the metal it owns outright. The Bank uses its own metal to adjust monetary levels in 65 percent of months, and these adjustments cause the level of monetary liabilities backed by unencumbered metal (M_U) to range from a high of 12 million (60 percent) in 1751 to a low of 0.6 million (2.5 percent) in 1763 (see Figure 4). Sometimes, purchased metal seems to offset low receipt levels: consider the years around 1750 or 1770. In contrast, when receipt levels were strong, the Bank seems to have run out of metal to sell. The Seven Years War (1756-1763) appears an extreme example. The Bank frequently alters the stock of bank money through adjustments in metal owned outright, and the plots suggest that this activity sometimes offset swings in receipt funding.

The third component is money backed by loans less equity (M_L). The series exhibits strong seasonal variance, but it has more stability in the long term than do the two metallic series. Until 1760, the Dutch East India Company routinely owes the Bank a few million bank florins in revolving credit. Then, for two decades, the Company repays most advances within a year. Starting 1780, lending to the Company and then to the City of Amsterdam grows quickly because of the Fourth Anglo-Dutch War. This regime change coincides with a collapse in receipt funding, default by the Company, and the permanent decline of the agio (Quinn and Roberds 2016).

Interpretation, however, needs to recognize that changes in these series are somewhat ambiguous. The Bank is complex and unusual events occur. A few times in our sample, the Bank reduces the deposit price of domestic gold coins. Existing receipts using the old price suddenly become "out of the money" and are abandoned in large numbers. These events transfer bank florins from M_E but are not withdrawals, and they move florins to M_U but are not purchases. Instead, the changes belong to a broader set of actions that reduce M_E and augment M_U.

Also, the Bank does not record intent. For example, the Bank collects fees and interest through the destruction of liabilities. The City, however, prefers to collect this profit as a payment in coin instead of balances. As a result, the Bank intermittently purchases coins for disbursement to the City. Over time, these additions to M_U anticipate future shocks to M_L, but the goal of enabling profit taking is never assigned to a specific purchase. Neither are other possible motivations such as sterilization. Instead, it all combines into additions to or drainage from M_U, so the next section turns to statistical analysis to better ascertain the motivations and effects of the Bank's actions.

5 Econometrics

We fit several econometric models to the reconstructed data series, with the goal of better understanding the Bank's policy (open market) interventions. For these exercises, it would be extremely convenient if all fluctuations in the monetary component M_U could be assigned to the Bank's OMOs. Unfortunately, as noted above, difficult-to-model factors such as receipt expirations and the City's profit-taking also impact M_U. There are also many months in the sample where only "maintenance" open market operations seem to occur, e.g., small purchases by the Bank to balance the contractionary effects of the fees it charged for receipts, or sales of small amounts of precious metals to supply jewelers and similar users. Finally, the Bank's archives provide little guidance as to what motivated the Bank to sometimes undertake larger interventions.[19]

As a first pass at understanding the Bank's policies, we divided the sample into three observable regimes, based on the sign and magnitude of the Bank's net interventions over a given month: 1) a "draining liquidity" regime (consisting of months where the Bank substantially reduced the stock of bank money through unencumbered metal sales), 2) an "adding" regime (months with substantial net unencumbered metal purchases), and 3) a regime of "no intervention" (months with neither draining nor adding). Draining (adding) was defined as a monthly rate of open market sales (purchases) in excess of 25,000 florins. The 25,000-florin filter was chosen so as to screen out months where only maintenance-type open market transactions occur, the idea being that larger operations were more likely to result from purposeful policy interventions.

The sample Markov transition matrix π for the three regimes (draining, adding, no intervention) is given by

$$\pi = \begin{bmatrix} .525 & .0667 & .408 \\ .057 & .631 & .312 \\ .119 & .107 & .774 \end{bmatrix},$$

where $\pi(i,j)$ gives the probability of transition from regime i to regime j. The corresponding steady-state distribution over regimes is (.179, .210, .611), i.e., under this classification, the Bank intervened heavily during about 40 percent of our sample (261 out of 672 months), with interventions roughly evenly split between sales and purchases. Regimes are moderately persistent, and it is rare for the Bank to go directly from adding to draining liquidity, or vice versa.

[19] A better understanding of the Bank's motives could doubtless be achieved through further study of the Bank's ledgers. The ledgers, which record millions of transactions over our data sample, provide a "footprint" of the Amsterdam bill market and conditions experienced in this market. For reasons of practicality we defer such study to future research.

5.1 What motivated interventions?

Why did the Bank of Amsterdam intervene? To investigate this question, our initial approach was to fit discrete choice (multinomial logit) models to each of the three regimes in the sample. The models estimate the probability of transitioning to a regime of (tightening, easing, or no intervention) during the following month, as a function of variables observed during the current month.

Because these models tend to be weakly identified, only sparse specifications were estimated. Explanatory variables include the current month's regime (i.e., a separate logit model is estimated for each regime), changes in money backed by encumbered coin ΔM_E, and changes in money backed by loans ΔM_L.[20] For months where draining or adding occurs, the size of the intervention is included in the explanatory variables. The model also includes two relevant market prices: 1) the market agio, and 2) the projected annualized return on bills of exchange circulating between Amsterdam and London (see Appendix B). Since most agio observations fall within a fairly narrow range, we reduced the agio series to indicators for "low" agios (i.e., below 3.7 percent or the 25th empirical percentile) and for the no-intervention regime, "high" agios (above 4.8 percent or 75th percentile). Bill rates include a lag. Finally, because open market operations were sometimes constrained by the Bank's stock of unencumbered metal, this was included as an explanatory variable for transitions from the "no intervention" state. The metal stock variable was split into two interaction variables, according whether a low agio (<3.7) was prevalent or not.

Estimates of the choice models are presented in Table 4. For each model, the "default choice" (necessary due to the usual incomplete identification of logit model parameters) was taken to be the current month's regime. The results seem intuitive, although the explanatory power of the models is low as measured by pseudo-R^2. In the no-intervention regime, interventions appear to key off the stock of unencumbered metal: a large unencumbered metal stock increases the chance of draining, but diminishes the chance of adds. Draining is more likely when a large metal stock is combined with a low agio. Absent the interaction with the metal stock, a low agio is estimated to reduce the chance of both draining and adding operations. On the other hand, a high agio increases the chances the Bank will add liquidity.

When the current regime is draining (or adding), transitions are impacted by the size of the Bank's operations, which diminish the probability of transition to the no-intervention regime. In other words, the Bank apparently preferred to spread its larger open market interventions over a period of time, a familiar practice in modern central banking.

[20] The estimation results reported in this section use a seasonally adjusted M_L (money backed by loans series). The seasonal adjustment procedure is described in Appendix B.

Table 4: Multinomial logit models of transition probabilities:
Posterior means (standard deviations) of coefficients

		Next month's regime					
Current month's regime	Explanatory variable	Draining		Adding		No intervention	
Draining	Constant			**-2.36**	(1.16)	0.663	(.629)
	Agio < 3.7%			**-2.26**	(1.52)	-.446	(.541)
	Bill rate			0.187	(0.189)	-0.0121	(0.0959)
	Bill rate (-1)			-0.0958	(0.173)	-0.0352	(0.0925)
	Δ Encumbered coin=ΔM_E			**-1.59**	(.851)	-0.362	(0.311)
	Δ Loans=ΔM_L			-0.590	(1.12)	-0.107	(0.595)
	Amount sold			-1.10	(1.31)	**-2.05**	(.806)
Pseudo- R^2 (Estrella measure) = .106							
Adding	Constant	**-2.89**	(1.23)			-0.457	(.572)
	Agio < 3.7%	.0132	(1.52)			0.674	(0.779)
	Bill rate	0.246	(0.202)			0.0856	(0.105)
	Bill rate (-1)	-.0239	(0.163)			-.0286	(0.0923)
	Δ Encumbered coin=ΔM_E	0.573	(.662)			0.262	(0.339)
	Δ Loans=ΔM_L	-0.645	(1.06)			-0.130	(0.553)
	Amt purchased	**-7.45**	(4.65)			**-3.25**	(1.38)
Pseudo- R^2 = .100							
No intervention	Constant	**-2.87**	(0.612)	**-1.55**	(0.544)		
	Agio < 3.7%	**-2.14**	(1.20)	**-3.63**	(1.24)		
	Agio > 4.8%	-0.640	(0.420)	**0.679**	(0.409)		
	Bill rate	-0.0403	(0.0814)	**0.156**	(0.0797)		
	Bill rate (-1)	0.141	(0.0860)	-0.0287	(0.0870)		
	Δ Encumbered coin=ΔM_E	0.206	(0.222)	-0.391	(0.240)		
	Δ Loans=ΔM_L	-0.587	(0.559)	-0.626	(0.540)		
	M_U*(agio<3.7)	**0.574**	(0.326)	0.505	(0.368)		
	M_U *(agio≥3.7)	**0.152**	(0.0629)	**-0.215**	(0.0735)		
Pseudo- R^2 = .125							

Notes: Estimates reported above were calculated using the BRMS package in the R programing language (cran.r-project.org/web/packages/brms/vignettes/vignettes/brms_overview.pdf). Diffuse priors over model coefficients were employed for each model estimated. Estimates for each parameter are from four chains with 1,000 draws per chain, each preceded by 1,000 burn-in draws. A coefficient in **red (blue) boldface** indicates that the 95% (90%) credible interval ("Bayesian confidence interval") for that coefficient does not contain zero.

Figure 5 plots the evolution of the 1-month-ahead transition probabilities implied by the logit models (at the posterior mean coefficients).

<Figure 5 here.>

The figure suggests that the Seven Years' War was a turning point for the Bank. Draining in particular is fairly likely over the first part of the sample but becomes more improbable from late 1762 through 1770, and again from 1783 onward. After about 1760, the Bank appears to increasingly rely on the forces of arbitrage.

5.2 VAR approach

Another methodology we applied to understand the Bank's interventions was to fit a VAR model to the data series described in the previous section. The estimated VAR includes five variables. These are the three components of Bank money balances: M_E, M_L, and M_U, plus the market agio, and bill rates.[21] An advantage of the VAR is that it allows for a more granular analysis of the Bank's actions than do the discrete choice models, but because fluctuations in M_U are driven by factors other than the Bank's OMOs, the VAR cannot give a perfectly clean "read" on policy effects. Although it is possible to estimate separate VARs over the three regimes defined above, specification tests strongly indicate that VAR coefficients are stable over the three regimes (see Appendix E). Hence results from a single VAR are reported..

For simplicity, the VAR was left unconstrained and was estimated by OLS, under the usual diffuse-prior interpretation of such estimates. Dynamics among the five data series are well captured by a specification with two monthly lags. The financial market variables (agio, bill rate) come first in the (Choleski) orderings shown below, the intuition being that these would react quickly to changes in international conditions and market sentiment. The monetary variables come second, the intuition being that these could be somewhat slower to react than market prices. Estimated impulse responses are robust to changes in orderings within the two classes of variables.

Figure 6 presents estimated 36-month impulse responses for the VAR. Units shown are percent for price variables and millions of bank florins for the monetary variables. Posterior mean responses and 70 percent error bands are shown.

<Insert Figure 6 here.>

The figure indicates that M_U responds principally to its own shocks, to shocks to the agio (column 1 of the impulse response array), and to shocks to M_E (column 4). Responses of M_U serve to partially offset the corresponding response of M_E. For example, a 1-standard-deviation (30 basis point) upward shock to the agio is estimated to induce a 400,000-florin decline in M_E, which is partially offset by a 200,000 increase in M_U.[22] A similar pattern occurs with shocks to M_E, with inflows of trade coins offset by drains and outflows by adds. For a few months of the sample, this pattern results from the expiration of large numbers of receipts, which would have induced opposite changes in M_E and M_U. The prevalence of such offsets throughout the sample, however, is consistent with their resulting from a deliberate policy on the part of the Bank.

[21] Additional information on the VAR models is provided in Appendix E.

[22] Note that the predicted outflow of encumbered coin in response to a positive agio shock runs contrary to the specie-flow story sketched out in Section 3.3. However, this outflow is (on average) offset by increases in the Bank's loans and unencumbered coin, leaving a close to zero net impact on Bank money. These patterns illustrate why it can be difficult to empirically measure specie-flow effects.

5.3 Counterfactual scenarios

For our final econometric exercise, we analyzed counterfactual scenarios over two policy-failure intervals. The first interval runs from December 1760 through July 1763, when the Bank's pace of metal sales slowed despite continued strong war-related demand at the receipt window.[23] In the counterfactual scenario, the VAR model was used to construct out-of-sample forecasts over this period, while constraining the path of deposits (i.e., coins under receipt) to match their yearend 1762 level. The conditional forecast gives an indication of what might have happened, if the Bank had continuously engaged in liquidity draining operations over this period while deposit inflow continued unabated.[24] The conditional forecast distributions are plotted in Figure 7, along with the implied distribution for total bank money.

<Figure 7 here.>

The forecasts suggest that a brisk pace of metal sales would have been necessary for the Bank to drain over this interval, totaling 3.2 million florins at the median forecast.[25] The projections in the figure do not incorporate the Bank's liquidity constraint, however. The projected amount of metal sales would have exceeded the unencumbered coin that the Bank had available to sell—only 1.4 million florins at the end of 1760. Sale of additional metal would have required either a loan to the Bank from the City (politically touchy) or the expiration of many receipts (unlikely).

The forecast scenario suggests that this sequence of interventions would have been partly successful in terms of returning the agio to its target range. The contractionary effect of the Bank's interventions is however blunted by a projected sharp increase in Bank loans, totaling about 2.4 million florins beyond their actual value by early 1763. As a result, forecasts of the total stock of Bank money remains close to their actual values, as do forecasts of Amsterdam-London bill rates.

Figure 8 plots the second policy-failure interval, which runs from July 1783 through December 1786. This period was characterized by another sudden deceleration in a sequence of asset sales that the Bank began in January 1783, conducted in an apparent attempt to neutralize a drop in the market agio.[26] The counterfactual scenario is constructed as a conditional forecast beginning in 1783:7 that constrains deposits to match their yearend 1786 level.

<Figure 8 here.>

[23] Another market dynamic begins in August 1763, with the outbreak of a financial panic in Amsterdam.
[24] In these forecast scenarios, we interpret changes in M_U as arising solely from the Bank's open market operations. In other words, we are assuming no significant expirations of receipts or profit taking by the City over the forecast interval.
[25] Median forecasts are shown in Figure 7 rather than means, due to skewness of the conditional forecast distributions.
[26] Our scenario stops well before 1788, when some trade coins begin to trickle back into the Bank due to political uncertainty.

The forecasts in Figure 8 project that a relatively modest pace of sales would have been necessary for the Bank to continue draining over the forecast interval: about one million florins at the median, out of an initial unencumbered money stock of 3.8 million florins in June 1783. This intervention is projected to keep the agio above 3 percent, rather than allow a decline to 1.9 percent as actually occurred.

While it would have been possible for the Bank to implement this level of intervention, there are reasons it may have been hesitant to do so. The forecasts in Figure 8 project a 2.5 million florin reduction in Bank money backed by loans M_L. In actuality, the majority of credits held by the Bank were Company debts in a politically induced state of non-performance (De Korte 1984, Quinn and Roberds 2016). If we recalculate the forecasts in Figure 8 while holding M_L at its actual level, then the projected reduction in M_U rises to 2.5 million florins, which pushes the Bank's stock of unencumbered metal down to 1.2 million, dangerously close to exhaustion.

5.4 Summary

Taken together, the results in this section suggest the following narrative of the Bank's open market operations. A key variable guiding the Bank's interventions appears to have been its stock of unencumbered metal (Table 4, panel 3). If this was sufficiently high (low), then the Bank would opportunistically sell (purchase) metal depending on market conditions: a low agio for sales, or normal agio for purchases. Once the decision was made to enter the market, large interventions were made in a smooth fashion (Table 4, panels 1 and 2), and these leaned against the prevailing flow of deposits (Figure 6). This approach to intervention met its limits during the Seven Years' War, when the Bank lacked adequate unencumbered metal to respond to large deposit inflows (Figure 7). The Bank became less likely to engage in draining operations in the second half of the sample (Figure 6). This passive approach worked for a while but could not counteract the Bank's loss of credibility in the wake of the Fourth Anglo-Dutch War (Figure 8).

Our twenty-first century characterization of the Bank's operations is necessarily anachronistic, and we cannot dismiss the possibility that the Bank's managers were guided more by profit-taking rather than by public policy motives. There is also a large amount of unexplained persistence in the Bank's choice of whether and how to intervene. Whatever their intent, however, the practical implication of the Bank's operations is clear: in its role as a central bank, the Bank functioned well when it could control liquidity creation, and less so when it could not.

6 Conclusion

The data presented above indicate that even in the eighteenth century, it was no simple matter to sustain a low interest rate regime. The Bank of Amsterdam did not just fix its policy rate and hope for the best. Instead, the data show that liquidity created through the Bank of Amsterdam's lending facility (i.e., its receipt window) was intensively managed by means of the Bank's open market operations.

Adherence to a low policy rate brought with it advantages and disadvantages. On the one hand, the Bank depended on its lending facility and its attractive interest rate to anchor the value of its money. On the other hand, market utilization of this facility could be volatile, particularly when the market price of Bank money (i.e., the agio) was low, or its outlook uncertain. Demand for Bank credit was also subject to fluctuations in bimetallic ratios, the outcome of wars, and similar exogenous factors. There is evidence that the Bank's open market operations counterbalanced the resulting fluctuations in the stock of Bank money, but the Bank's sales operations were limited by its level of unencumbered assets. As a result, the value of the bank florin proved vulnerable to a combination of pessimistic expectations and low levels of owned assets.

A low interest rate policy was thus both a source of the Bank's success and a contributor to its demise. Cheap access to credit made the Bank's lending facility popular and promoted agio stability over long periods, yet this same popularity could also undermine stability or fail altogether. Large-scale open market sales were the Bank's primary tool available to address problems with its lending facility, but the Bank did not sacrifice immediate stability and profitability to maintain a sufficient precautionary stock of assets. In the end, the Bank failed because it did not anticipate the degree of tightening necessary to support the credibility of its policy framework. That experience may offer a useful lesson for present-day central banks.

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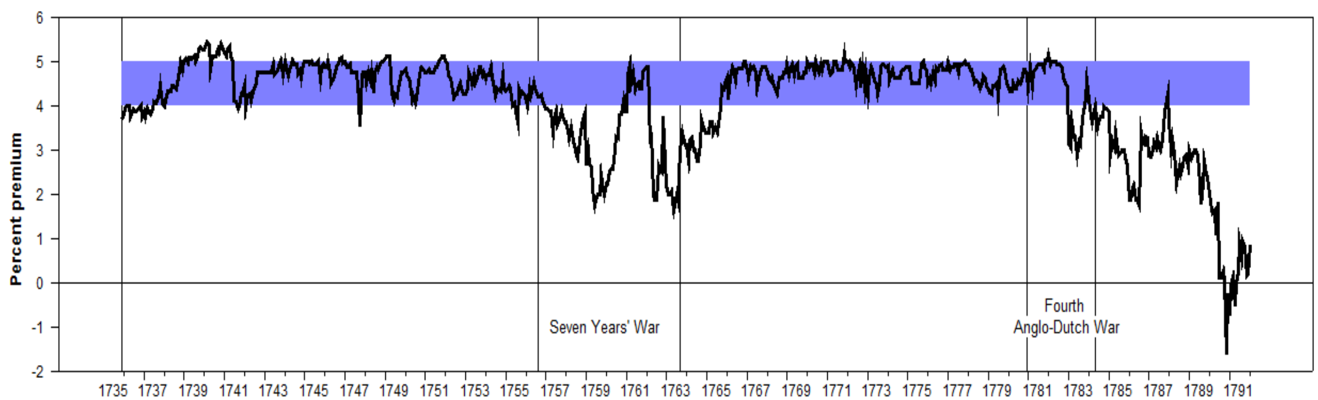
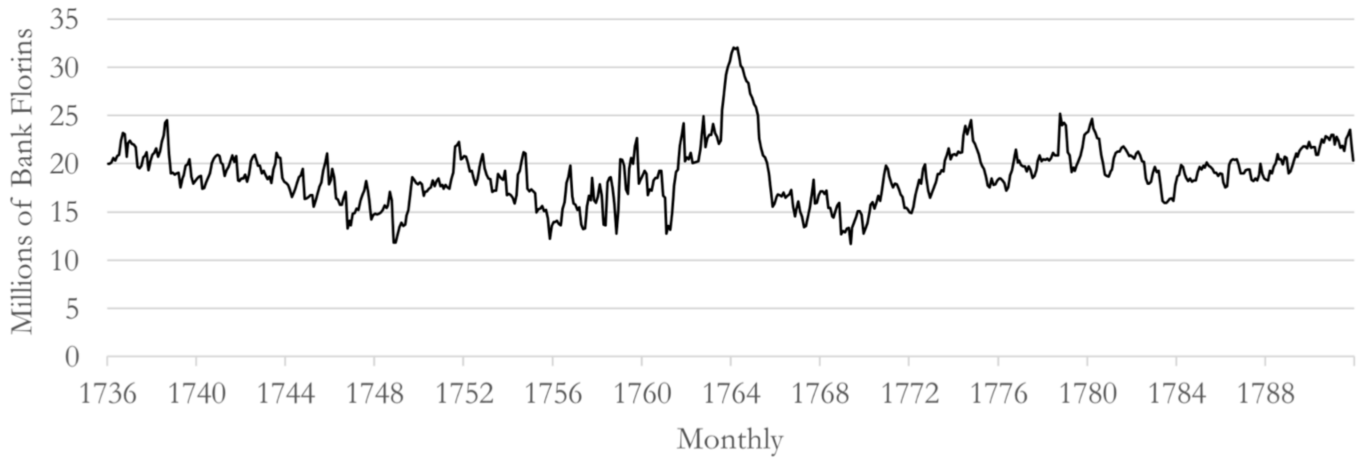
Figure 1: Market agio, 1735:12-1792:1
(Percent premium bank florin over current florin)



Notes: The shaded band represents the Bank's unofficial target band. The Seven Years' War period is taken as August 1756 (the first Prussian campaign of the war) through July 1763 (the outbreak of the postwar financial panic in Amsterdam). The Fourth Anglo-Dutch War period is taken as December 1780 (declaration of war) through May 1784 (signing of the Treaty of Paris). The series shown in the figure is augmented by one month at the beginning and end of the archival data sample to reflect the date conventions in the archival data.

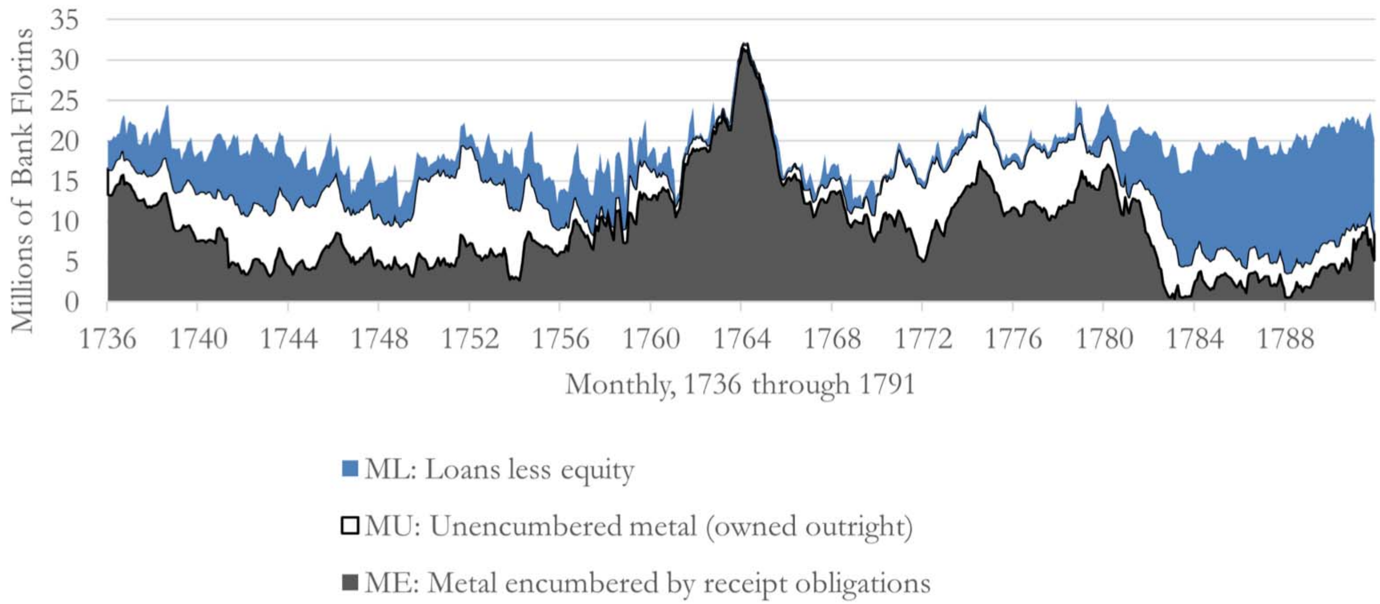
Sources: Gillard (2004) and Schneider, Schwarzer, and Schnelzer (1991).

Figure 2. Monetary Liabilities from 1736 through 1791



Sources: Amsterdam Municipal Archives and authors' calculations.

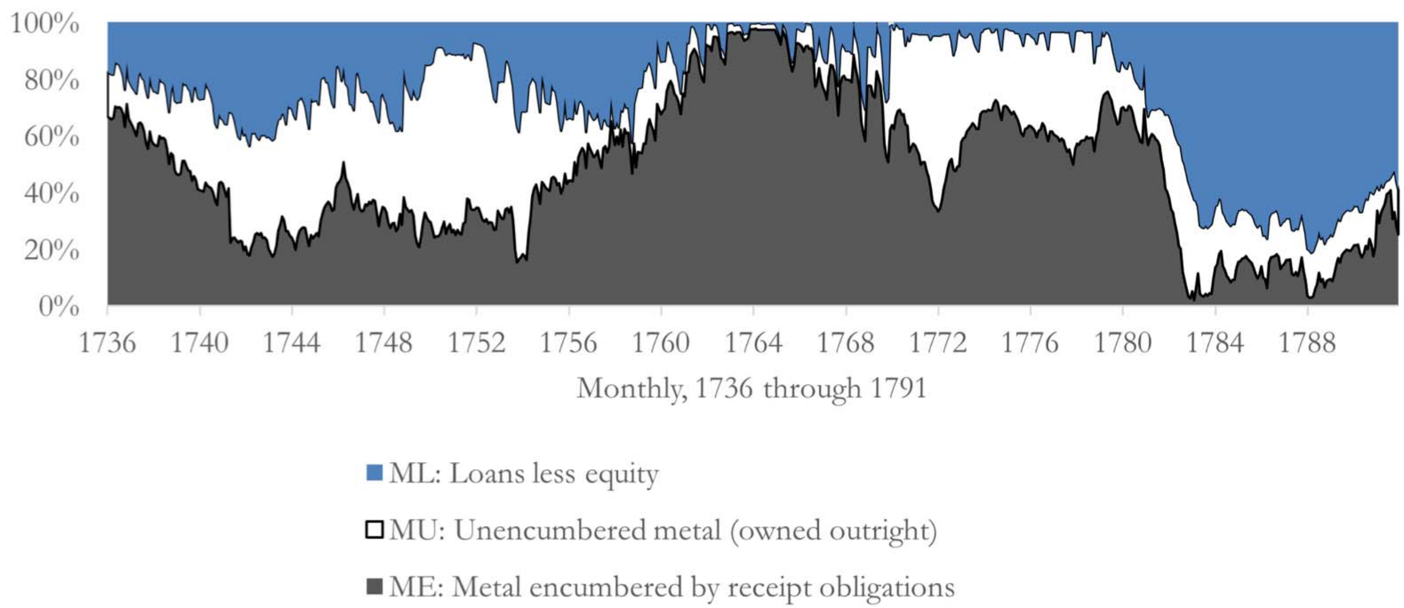
Figure 3. Backing of Monetary Liabilities



Note: for seven months of the sample, M_L is slightly negative.

Sources: Amsterdam Municipal Archives and authors' calculations.

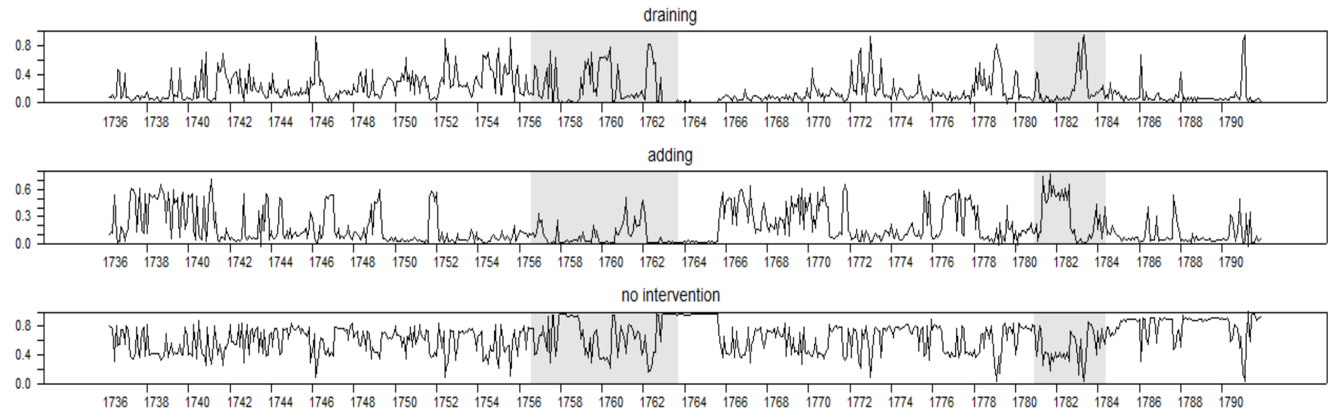
Figure 4. Share of Monetary Liabilities by Backing



Note: for seven months of the sample, M_L is slightly negative.

Sources: Amsterdam Municipal Archives and authors' calculations.

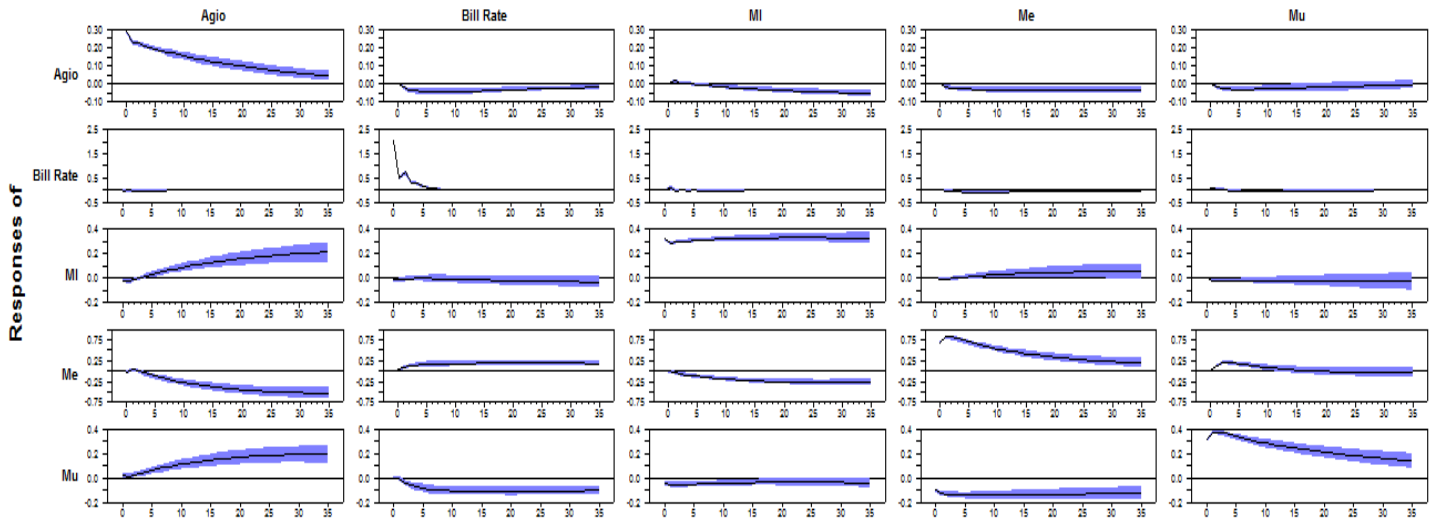
Figure 5: One-month ahead transition probabilities, 1735:12-1791:12



Notes: one-month ahead probabilities calculated at the posterior mean values reported in Table 4; wartime intervals shaded.

Source: authors' calculations.

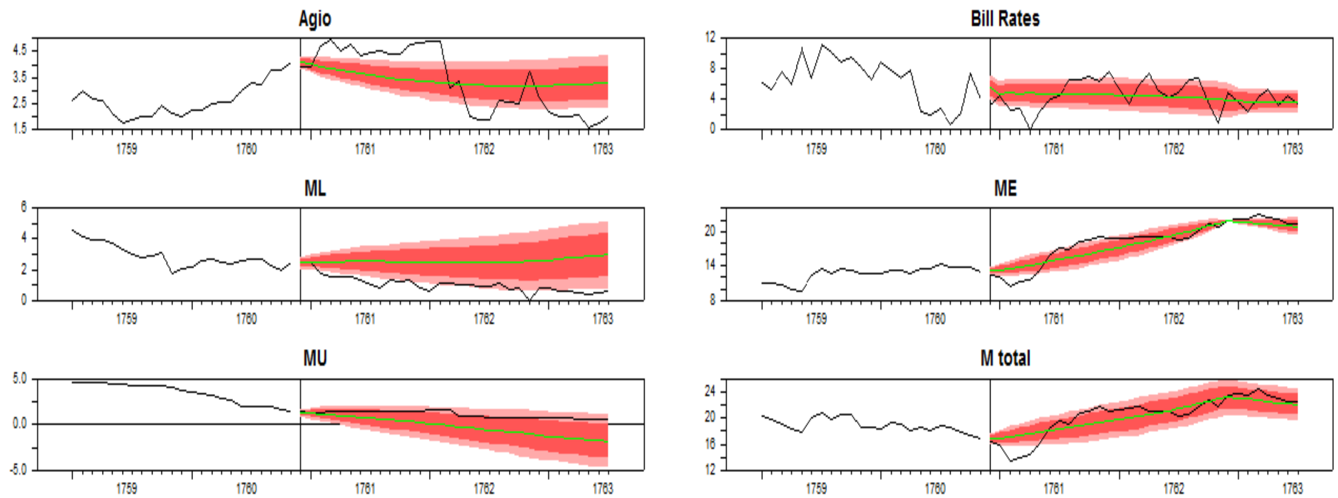
Figure 6: Impulse responses



Notes: units are percent for prices and millions of bank florins for quantities. 36-month responses to 1-standard deviation shocks (posterior means and 70 percent error bands, based on 1000 draws) are shown.

Source: authors' calculations.

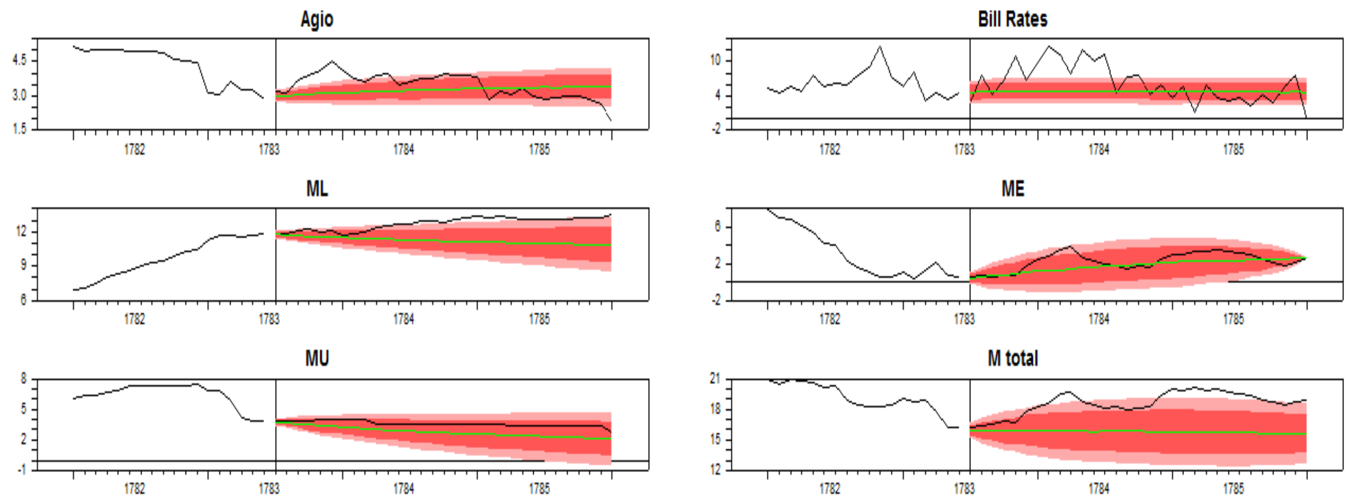
Figure 7: Conditional forecasts versus actual series, 1760:12-1763:7



Notes: forecast distributions are calculated using Algorithm 1 of Waggoner and Zha (1999, 642). Distributions are from 10,000 draws of the Gibbs sampler, with 10,000 burn-in draws. Shown are the median (green lines), the middle 50 percent (red band), and middle 70 percent (pink bands) of the forecast distribution for each variable, together with the actual data series (black lines). Units are percent (prices) and millions of bank florins (quantities).

Source: authors' calculations.

Figure 8: Conditional forecasts versus actual series, 1783:7-1786:12



Notes: forecast distributions are calculated using Algorithm 1 of Waggoner and Zha (1999, 642). Distributions are from 10,000 draws of the Gibbs sampler, with 10,000 burn-in draws. Shown are the median (green lines), the middle 50 percent (red band), and middle 70 percent (pink bands) of the forecast distribution for each variable, together with the actual data series (black lines). Units are percent (prices) and millions of bank florins (quantities).

Source: authors' calculation.

Appendices

Appendix A: Construction of Bank of Amsterdam balance sheets

Appendix B: Additional details of data series

Appendix C: The use of receipts

Appendix D: The impact of bimetallic ratios on Bank operations

Appendix E: Additional details of the VAR models

Appendix F: Receipts at the Bank of Amsterdam versus discounts at the Bank of England

Appendix A: Construction of Bank of Amsterdam balance sheets

The cashbooks (*kasboeken*) for 1747 through 1760 are not extant, so we do not have starting levels of

- collateral
- withdrawals and prolongations by collateral
- purchases and sales by collateral
- payments to the city treasury
- expenses

Therefore, we cannot directly connect these to master (*specie kamer*) account transactions. For each account entry, however, we do have date, name, amount, and sequential position. The challenge is to use this information to best assign a purpose to each ledger transaction. This appendix sets out our filtering process.

I. Dutch East India Company Loans

Using name information and annual totals, we know Dutch East India Company loan principal and interest payments. These ledger transactions are readily sorted out, and their totals can be confirmed by fiscal year (see Van Dillen 1925, 979-984).

II. Annual Transaction Fees

At the end of each fiscal year, account holders had to pay a fee assessed on the number of debit transactions. The Bank deducted the total of all these fees from the master account (*specie kamer*) as the last transaction of the fiscal year. It was labeled *partygeld* and is readily identifiable.

The remaining transactions are (usually) either deposits/withdrawals of coins, prolongations of coins, or purchase/sales of collateral that is not under receipt.

III. Deposits and Purchases

The Bank had a long-standing tradition of channeling deposits through receiver accounts. Receivers than transferred cumulative deposits to the debit side of the master account (*specie kamer*). In contrast, the Bank accounted for purchases directly with its counterparty. This accounting convention bifurcates deposits (receiver as counterparty) from purchases (other people as counterparty).

IV. Withdrawals and Prolongations

The credit side of the master account, however, has no such separation. Withdrawals, prolongations, and sales are mingled. The major tool for identifying withdrawals and prolongations comes from regularities in how the receipt window operated. Van Dillen observed that deposits, withdrawals and prolongations occurred in a unit called a sack that had a highly consistent value over time (Van Dillen 1925, 883-884). We have confirmed this through reconstruction of extant *kasboeken* for numerous years. The Bank of Amsterdam seems to have migrated to units of sacks in the early 1700s.

- For Dutch coins, the value of a sack is the official value of each coin in bank florin multiplied by the number of coins per sack.
- For foreign coins, the value of a sack is the bank florins per mark of the silver or gold in bank florin multiplied by the number of marks per sack.

Withdrawal and prolongation fees were assessed per sack at a consistent rate. Hence, from the perspective of sacks of coins, withdrawals and prolongations occur in discrete bank florin increments as reported in the table below.

Table A.1. Withdrawal and Prolongation Values in Bank Florins: 1736-1769

	Sack Content	Sack Value in bank florin	Fee Rate	Withdrawal with Fee in bank florin	Prolongation Fee in bank florin
Dutch Coins					
Ryxdaalder (Silver)	200 coins	480	1/4%	481.2	1.2
Silver Ducatons	200 coins	600	1/8%	600.75	0.75
Staten Drie Gulden (Silver)	200 coins	565	1/8%	565.7	0.70625
Goude Ducaaten (Gold):	1,000 coins				
1736 through 1746		4,950	1/2%	4,974.75	24.75
1747 through 1749		4,975	1/2%	4,999.875	24.875
1750 into 1756		4,950	1/2%	4,974.75	24.75
1756 through 1769		4,975	1/2%	4,999.875	24.875
Foreign Coins					
SILVER (approximately 92.5% fine): Pylaaren, Mexicaanen, and Sivil-iaanen (Spanish dollars of various origins); Franse Croonen (French); Navarre Croonen (French); Engelse Croonen (English);	100 marks (weight)	2,200	1/4%	2,205.5	5.5
GOLD (approximately 22 carats fine: 91.67%) Goude Crusados (Portuguese); Goude Guignes (English); Goude Franse Schild Pistoolen (French); Goude Brabantse Soveryne (Brabant)	22 marks (weight)	6,820	1/2%	6,854.1	34.1
GOLD (approximately 21.33 carats fine: 88.89%) Goude Franse Pistoolen (French)	22 marks (weight)	6,600	1/2%	6,633	33

Using this regularity to label account transactions is complicated by a few details.

1. The bank florin value per sack can change. This happened to gold *ducaton* sometime between 1746 and 1761. To address this, we treat gold *ducaton* as two coins: one at the 1746 value and one at the 1761 value.
2. Some types of coin have the same bank florin value, so they are indistinguishable in account terms. To address this, we combine coin types of the same bank florin value into one category.
    - Spanish, French, and English silver become "Foreign Silver Coins" at 2,200 bf per sack with a fee rate of ¼%.
    - Gold coins with 22 carat fineness aggregate into "Foreign Gold Coins" at 6,820 bf per sack with a fee of ½%.
3. Some values are multiples of others. Multiples do not stop our identification of transactions as withdrawals or prolongations, but they do confuse identification of which coin was withdrawn or prolonged.
    - Withdrawal multiples are rare. Examining all combinations in 1746 where neither coin exceeds 100 sacks, we identified only two multiples for withdrawals. One is the highly unlikely withdrawal amount of 308,434.5 bf being either 62 sacks of gold ducaton (1746) or 45 sacks of foreign gold coins. The other is the far more common 26,466 bf being either 55 sacks of Ryxdaalders or 12 sacks of Foreign Silver Coins. This outcome may have to become its own category should it arise and no additional information is available.
    - Prolongation multiples are more common. For example, 6 bf could prolong either 8 sacks of silver ducatons or 5 sacks of ryxdaalders. This is an ambiguity we will likely be unable to resolve with confidence, but it does not impede our ability to categorize a transaction as a prolongation.
4. The Dutch silver coin called the "*Staten Drie Gulden*" has a rounding problem. They have a per-sack fee of 0.70625 bf, but the Bank only handled increments of 0.025 bf (1/40th). Examination of *staten drie gulden* transactions from 1761 through 1764 (there were none in 1746), suggests the Bank usually rounded to the nearest 1/40th. However, the Bank would sometimes round up when rounding down was slightly more appropriate. As a result, we look for expected *drie gulden* values and known rounding deviations.

Although all coins using receipts were transacted in sacks, the Bank's account system operated in bank florins rather than sacks. As a result, the sack-based accounting of coins did not always lead to a unique bank florin entry.

For example,

- A withdrawn sack of foreign silver could be paid by one transaction of 2,205.5 bf. Or, two people could <u>split</u> the payment, i.e. one pays 1,205.5 and the other pays 1,000. Alone, neither corresponds to a sack withdrawal or prolongation derived from Table A.1.

- Alternatively, a person could pay 2,205.5 to withdraw one sack of foreign silver and, separately, pay 481.2 to withdraw one sack of *ryxdaalders*. Or, a person could combine them into one payment of 2,686.7. The combination does not corresponds to a sack withdrawal or prolongation derived from Table A.1.

Such splits and combinations interfere with the simple translation of account transactions into collateral transactions. To ascertain the extent of these problems, we matched all account transactions in 1746 and 1761 (our bookend years) with collateral transactions.

1. We found no examples of combining. We know this does happen in later decades, but it may not be happening at mid-century.
2. Prolongations of a given coin type were not split, so prolongations should be readily identifiable.
3. Withdrawals of the same coin type were sometimes split. This problem is surmountable because splits were all booked on the same day and because the elements of those splits were recorded (often in sequence) in the accounts ledger. For example, on 24 November 1746, Elias Barents withdrew 6 sacks of Spanish silver coins worth 13,200 bank florin in principal. He also had to pay 33 bank florins in fees. This withdrawal was paid for by a sequence of consecutive transactions reported in Table A.2. The "voor idem" means that an entry was made on behalf of Elias Barents.

Table A.2. Changes in Bank of Amsterdam Balance Sheet from a "Split" Withdrawal

ASSETS		LIABILITIES	
6 sacks of Spanish pylaaren coin to:		Account Balances from:	
Elias Barents	-13,200	Elias Barents	-6,025
		Eliazar Barents voor idem	-850
		Barent Symons voor idem	-3,000
		Gerrit Muller voor idem	-3,358
		NET WORTH (Profit)	
		Profit from:	
		Withdrawal fee	33
TOTAL CHANGE	-13,200		-13,200

Sources: (5077/1387, f. 65), (5077/1344, f. 89)

Applying these insights form the *kasboeken* creates a highly effective filter for withdrawals and prolongations for the years 1747 through 1760.

V. Test of the Filter

Before applying the withdrawal/prolongation filter (Section IV above) to the years 1747-1760, we applied it to the three years with *kasboeken*. We then compared the filter result to the actual record. Table Y gives the results. Overall, the filter mis-identified 9 out of 2,955 transactions. That makes for an error rate of 0.30 percent measured by transactions and 0.24 percent measured by bank florins.

Over the three years, the test incorrectly rejected 47 transactions that were in fact withdrawals/prolongations. Most of that was human error in not accepting that very large prolongations as such. This was corrected when applying the filter to the gap years. The remaining 8 rejection errors were from combining withdrawal and prolongation (thrice), aggressive rounding of *staten drie gulden* coins (thrice), an unexplained fee error, and a fee error that was later corrected. Over the three years, the test incorrectly accepted one sale transaction. A 125 bank florin transaction was labeled as the prolongation of *staten drie gulden* when it was really part of the sale of gold coins.

Table A.3. Results of Filter Test on the Years 1744-1746.

ACTUAL SPECIE KAMER CREDITS BY CATEGORY

BY TRANSACTIONS	1744	1745	1746	Total
Withdrawals and Prolongations	698	885	1,131	2,714
Sales	76	19	146	241
Total	774	904	1,277	2,955

BY BANK FLORINS	1744	1745	1746	Total
Withdrawals and Prolongations	3,845,428.825	4,016,138.750	9,004,322.30	16,865,889.875
Sales	183,644.125	25,824.400	2,404,616.20	2,614,084.725
Total	4,029,072.950	4,041,963.150	11,408,938.50	19,479,974.600

INCORRECT REJECTIONS OF A CREDIT AS A WITHDRAWAL OR PROLONGATION

BY TRANSACTIONS	1744	1745	1746	Total
Human Error	1	15	23	39
Filter Error	2	4	2	8
Total	3	19	25	47

BY BANK FLORINS	1744	1745	1746	Total
Human Error	627.00	63,880.18	281,618.30	346,125.48
Filter Error	15,471.50	12,812.25	18,102.80	46,386.55
Total	16,098.50	76,692.43	299,721.10	392,512.03

INCORRECT IDENTIFICATIONS OF A CREDIT AS A WITHDRAWAL OR PROLONGAITON

BY TRANSACTIONS	1744	1745	1746	Total
Human Error	0	0	0	0
Filter Error	0	0	1	1
Total	0	0	1	1

BY BANK FLORINS	1744	1745	1746	Total
Human Error	0	0	0	0
Filter Error	0	0	125	125
Total	0	0	125	125

SHARE OF CREDIT ENTRIES MISIDENTIFIED BY THE FILTER

BY TRANSACTIONS	1744	1745	1746	Total
Withdrawals and Prolongations	0.29%	0.45%	0.18%	0.29%
Sales	0.00%	0.00%	0.68%	0.41%
Total	0.26%	0.44%	0.23%	0.30%

BY BANK FLORINS	1744	1745	1746	Total
Withdrawals and Prolongations	0.40%	0.32%	0.20%	0.28%
Sales	0.000%	0.000%	0.005%	0.005%
Total	0.38%	0.32%	0.16%	0.24%

Source: Authors' calculations.

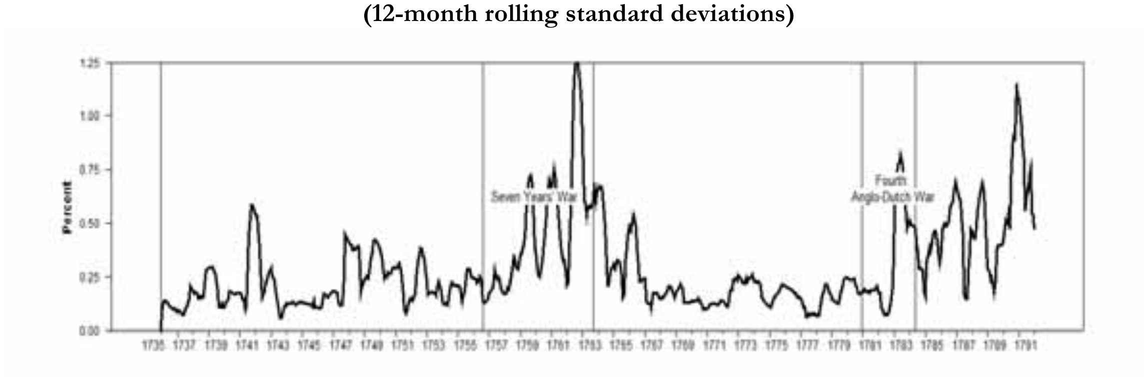
Appendix B: Additional details of data series

B.1 Agio

The data for agio series consist of monthly observations taken from on the market agio of the bank florin, i.e., the percent premium of the bank florin over the current florin. These are taken from Gillard (2004) and Schneider, Schwarzer, and Schnelzer (1991). When multiple observations were available for a given month, we averaged observations. In order to cover the entirety of the Bank's fiscal year, the agio dataset begins in December 1735 and runs through January 1792.

The volatility of the agio follows a roughly inverse pattern from its level, i.e., volatility increases whenever the agio falls out of its target range. This pattern is shown in Figure B.1., which plots 12-month rolling standard deviations of the agio series in Figure 1:

Figure B.1. Volatility of the agio, 1735:12-1792:1
(12-month rolling standard deviations)



B.2 Interest rates

There is no single reference short-term market interest rate for Amsterdam during our sample that would correspond to the rate on short-term government debt (e.g., 90-day T-bill rate) or related interest rate, as is commonly used in modern macro studies. A type of interest rate that is commonly used for this era is the "bill rate." In our case the bill rate is the return available to a merchant in Amsterdam from purchasing a bill of exchange drawn on a reputable merchant in another city (say, London), then repatriating the funds to Amsterdam by drawing a London bill on an Amsterdam merchant.

Because bills drawn in Amsterdam was payable in foreign currency, they always entailed foreign exchange risk. And, even when they were drawn on the best credits, they also involved some credit risk. Bills could be refused (fail to be accepted) by a drawee or an accepted bill could be defaulted on. Nor could a bill be formally bound to collateral. To compensate bill holders for these risks, the bill rate was typically much higher than the one-half percent charged by the Bank of Amsterdam at its receipt window (the average ex post bill rate in our sample is about 4.3 percent annualized) and this rate was also volatile (the sample standard deviation is 2.9 percent).

To construct a bill rate series, we used data on London prices of bills drawn on Amsterdam, taken from a dataset generously provided by Larry Neal, and Amsterdam prices of bills drawn on London, taken from Schneider, Schwarzer, and Schnelzer (1991).[1] Both of these series were originally collected from "price currents," local financial newspapers that appeared once or twice a week. The Amsterdam on London series is available only on a monthly basis, where the monthly observation was derived from the first available observation of that month. To construct a corresponding series for London, we took the nearest corresponding price observation, correcting for England's belated adoption of the modern calendar in September 1752. We again employed data from December 1735 through January 1792.

In both London and Amsterdam, bills on the other city were customarily drawn at multiple maturities, including "sight" (de facto 7-day) and 2-month (60-day) bills. We used 2-month bill prices to construct our interest rate series because they are many more observations available for these than for the sight bills, particularly for Amsterdam on London. Prices are recorded as "bank shillings" (= .3 bank florins) per pound sterling. Our interest rate thus corresponds to the return on a 4-month transaction: purchasing a 2-month bill on London in Amsterdam, then a 2-month bill on Amsterdam in London. The (measured) annualized ex post interest rate on such a transaction, expressed in percentage terms, is

$$r_t = 300\left(L_{t+2} - A_t\right)$$

where L_{t+2} is the log of the 2-month ahead London price of a 2-month bill drawn on Amsterdam, and A_t is the log of the current month Amsterdam price of a bill drawn on London. The literature traditionally calculates the ex ante bill rate as

$$300\,(L_t - A_t)$$

under the implicit assumption that logged bill prices (and the London price in particular) approximately follow a random walk. There are two potential problems with the traditional methodology in the present case. The first is that while the London on Amsterdam price series is complete, many of the Amsterdam on London prices are missing (302 observations or 45 percent of the sample) including all data after 1789. The second is temporal misalignment of the two bill price samples due to variation in calendars and irregular publication dates of the price currents. The data issues are potentially compounded by the underlying informality of price currents' data. The data gaps in particular are evident in figure B.2, which plots the two bill price series.

[1] We used London price data because Amsterdam-London was the densest market of its day. At the cost of additional complexity, our strategy could be adapted to take into account bill prices on additional markets.

Figure B.2: Bill price data series, 1735:12-1792:1
(100 x logs of raw series, bank shillings per pound sterling)

Visual inspection of figure B.2 indicates that the two bill price series are smooth and highly correlated, which suggests that a variation on the traditional method that can be used to resolve the data issues. To this end, we employed a simple state-space model, following the basic strategy of the well-known stochastic trend model of Hodrick and Prescott (1997).

In our model, there are two underlying state variables, x_t and z_t, both of which are postulated to follow univariate random walks; innovations in x and z may be contemporaneously correlated.[2] The observed (demeaned) Amsterdam on London bill price series is postulated to follow

$$A_t = x_t \ ,$$

and the (demeaned) London on Amsterdam bill price similarly follows

$$L_t = x_t + z_t \ .$$

The model is easily fit to the bill price data via maximum likelihood estimation of the Kalman smoother.[3] Figure B.3 plots the smoothed data series. Note that the smoothed London on Amsterdam series replicates the original data series.

[2] As in many applications of the Hodrick-Prescott filter, the random walk structure is used here as a convenient filtering device rather than as a precise description of the stochastic properties of the data.
[3] Our estimated model allowed for measurement errors in the observed bill rates. The estimated variance of these error terms was however so small as to be negligible, so we set them to zero.

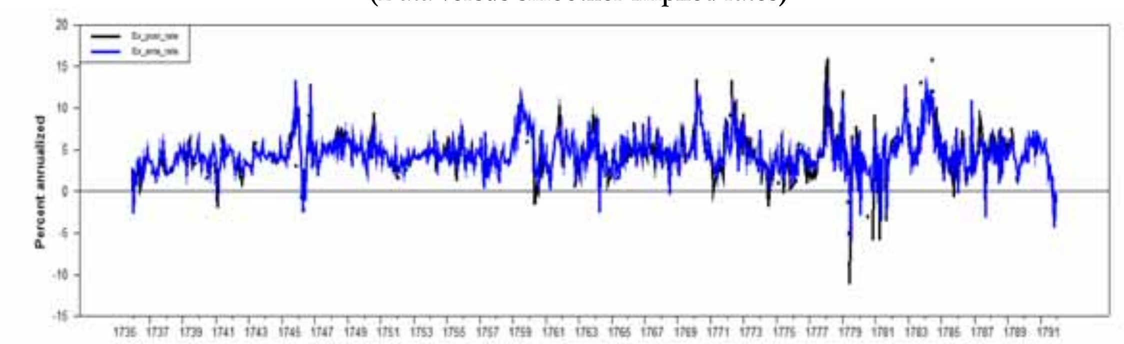
Figure B.3: Smoothed bill price data series (100 x logs), 1735:12-1792:1

With the smoothed series in hand, we then calculated ex ante bill rates $\hat{r}_t$ as

$$\hat{r}_t = 300\left(\hat{L}_{t+2} - \hat{A}_t\right)$$

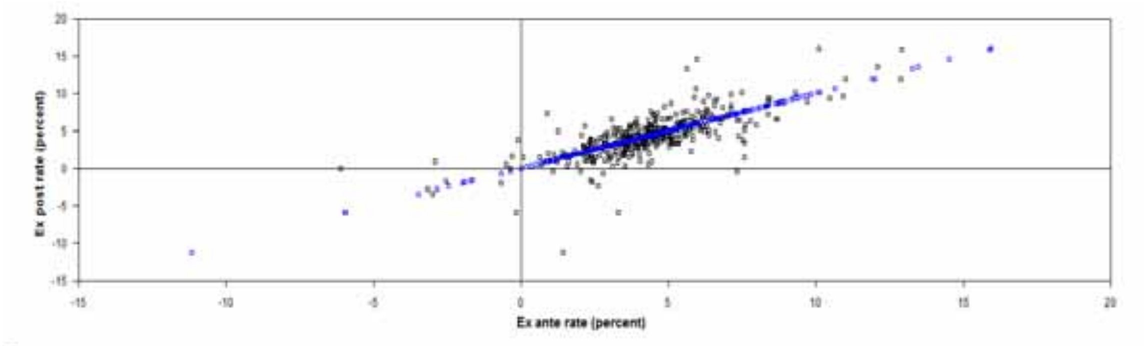
where $\widehat{A}_t$ is the smoothed value of the log of the Amsterdam on London bill price, and $\hat{L}_{t+2}$ is the 2-month ahead projection of the log price of London bills on Amsterdam. Our method thus follows the traditional approach in that each bill price is approximated as a random walk. What is new is that we assume the difference between the two prices is also approximated by a random walk, as a way of filling in the missing observations. Figure B.4 below plots the measured ex post rate r_t and our calculation of the ex ante rate $\hat{r}_t$ over the data sample.

Figure B.4: Ex post and ex ante bill rates, 1735:12-1792:1
(Data versus smoother-implied rates)



The ex ante rate tracks the ex post rate (the simple correlation of the two series is .73) except during periods of extended market volatility. An X-Y plot of the two series (Figure B.5) shows that the ex post rate is generally well predicted when ex ante rates are close to their mean. Our filtering approach does less well, however, at very high rates or for the subset of the sample when the round-trip returns on bills are negative.

Figure B.5: Ex post and ex ante bill rates
(Data versus smoother-implied rates)

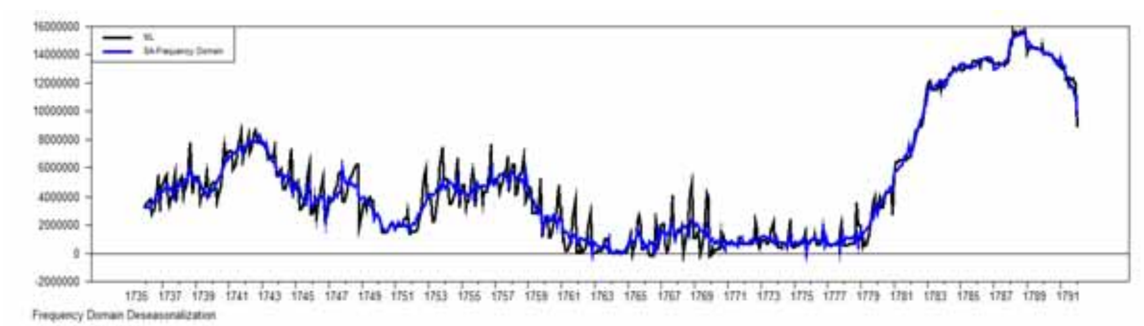


B.3 Seasonal adjustment of the Company loans series

The M_L series displays marked seasonality that does not appear in any of the other series analyzed in this study. To simplify the econometric analyses, the seasonal component of M_L was removed using the procedure described in Estima (2010, 438).

To implement this procedure, the loans series was prefiltered by demeaning, tapering at both ends, and padding with zeros out to 6144 observations. A band-pass filter was then applied to the finite Fourier transform of the prefiltered series. The filter masks out harmonic frequencies associated with annual cycles and adjacent frequencies. The prefiltering steps were then reversed to obtain a seasonally adjusted series. For three observations where the original series was at or near zero, "ghosting" distortions from the band-pass filter cause the adjusted series to go slightly negative. The negative observations have no economic significance and were set equal to zero in the filtered series. Figure B.6 plots the original and filtered series.

Figure B.6: Original and deseasonalized loans series, 1735:12-1792:1



Appendix C. The use of receipts

C.1 Description in a contemporary merchants' manual[4]

Since this business [with receipts] is known to only a few people, we will illustrate it with an example. Suppose that you had 1000 French Louis d'Or that you wanted so sell. These normally go for 11.4 to 11.7 florins [i.e., current guilders] each, but suppose you could not sell them for more than 11.4 florins. Since this price is too low and unprofitable for you, you bring these coins into the Bank, which dispenses in return for these [coins] 10,700 florins bank money, at 10.7 [bank] florins a coin, which you then have at your disposal for six months at a cost of ½ percent, six months being the usual maturity of receipts. If the coins in question appreciate in the meantime, and come up to a price where you find it profitable to sell, then you can withdraw these from the Bank and sell them at the going price; or, you can sell your receipt, if somebody wants to buy it at the corresponding price.

If, however, the coins in question do not appreciate within six months' time, and you are nevertheless of the opinion that they will go higher during the following six months, then you can prolong the receipt, provided you bring it into the Bank and transfer the 53.5 [bank] florins, that is, the ½ percent, from your account to the Specie Kamer [the Bank's master account], which you would be obliged to pay to the Bank for having stored your coin, according to the receipt agreement. After which it would be written on the receipt, *prolonged for six months on date* … . Then, after the passage of six more months, if you again want to prolong again, this can also be done, provided that you transfer 53.5 florins to the Bank as you did before. And this can happen several times over, for as long as you see some profit in it. In this way some amounts have likely been prolonged seven or eight times, from which one can easily understand that this [business] is profitable to the Bank. We are told that during 1714 and 1715, more than a million Louis d'Or were brought into the Bank; on these coins alone the ½ percent fee would be 53,500 florins, not counting prolongations.

We shall now show what profit or loss accrues to a banker who has brought in the 1000 Louis d'Or as in the example above. We have supposed that no more than 11.4 florins per coin was offered to him, by which he would could receive no more than 11,400 florins for his stock of 1000 coins.

Now the Bank dispenses to him for these

10,700 florins

And, applying an agio I assume to be 5 percent

535 florins

[4] Authors' translation of L'Espine and Le Long (1763, 197-202). L'Espine and Le Long illustrate the use of receipts with Louis d'Or, a large French gold coin that does not appear in the Bank archives after 1736. This example would therefore have been obsolete when this edition of the manual was published in 1763, suggesting that it was retained from an earlier edition.

Equals their total value in current money

11235 florins

Since this valuation of the 1000 coins is now 165 florins less than what he was offered, his receipt will cost him 0.162 florins per coin.[5] If he now, within six months (that being as long as his receipt runs without a prolongation), can get 5 or six stivers [.25 or .3 florins] more for every Louis d'Or, then he sells these and delivers the receipt, without conveyance or endorsement, to the buyer, who pays him in current money. And, if the buyer then has an opportunity to profitably sell these, he can take advantage of this opportunity at any time. In this way receipts can frequently go through 7, 8, or more pairs of hands within their specified maturity, without the need for any conveyance or endorsement.

If you want to withdraw the 1000 Louis d'Or from the Bank during the six months' maturity of the receipt—say because you want to send them elsewhere or because you sell them for current money—then you first have to compensate the Bank for the funds it advanced, that being in this case

10,700 [bank] florins

To which ½ percent must be added

53.5 florins

Totaling all together

10753.5 florins

For this sum you write a payment order to the Bank, *on your account*, and then bring this order to the Bank, and request the 1000 Louis d'Or in accordance with the receipt. The Bank bookkeeper, having received this, first researches whether there are sufficient funds in your account. Finding that there are, he immediately sends along a Bank servant to inform the Lord Commissioners of the Bank, that they may dispense to the bearer the requested 1000 Louis d'Or. One of the Lord Commissioners then goes to retrieve these, and transfers them to the person bringing the receipt, sealed [in a sack] with their weight inscribed on them, in return for the surrender of the receipt. At this point the matter is concluded.

It should also be mentioned that although you may have purchased a receipt for coins that were brought into the Bank by another, that you must still make out the order to the Bank *on your account* if you want to withdraw the coins. The name of the original depositor of the coin does not matter in the least; it is the holder of the receipt, regardless of who that may be, whose obligation it is for the value of the withdrawal, and therefore whose account must be debited.

There is sometimes heavy trading in receipts, primarily in [Spanish] Pieces of Eight, [Dutch] Ducatons, and [French] Louis D'Or. In the years 1714 and 1715, so many Louis D'Or were brought into the Bank, that receipts did not fetch more that 4 or 5 stivers [.2 to .3 florins] per Coin. In 1716 the price rose to 16 to 17 stivers [.8 to .85 florins] per Coin.

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[5] Literally, 3 Dutch stivers plus 4.8 pennies. This may be an arithmetic mistake, 0.165 florins would be 3 stivers plus 6 pennies.

C.2 An example of a "carry trade" funded with receipts

The value of the trading strategy described by L'Espine and Le Long (essentially, funding one's position in the Amsterdam bill market via the receipt window) can be illustrated with a simple example. Suppose there are two hypothetical investors in the Amsterdam bill markets. The initial endowments and the trading strategies of the two investors are as follows:

Investor 1 is endowed with a ryxdaalder coin worth 2.4 bank florins at the receipt window, as described in Table 2 above. He deposits this coin with the Bank and uses the proceeds to purchase a 2-month bill of exchange on London. When the London bill is paid, he uses the proceeds to purchase a 2-month bill on Amsterdam. When the Amsterdam bill is paid, he "cashes out" by either redeeming the receipt at a cost of ¼ percent or selling his bank florins in the spot market, whichever yields more current guilders (for purposes of this example we ignore the "liquidation value" of the receipt, which would still have 2 months to run, if Investor 1 chooses the latter option).

Investor 2 is endowed with a current guilder. He sells this in the spot market for bank money, and uses the proceeds to purchase a 2-month bill on London. When the London bill is paid, he uses the proceeds to purchase 2-month bill on Amsterdam. When the Amsterdam bill is paid, he "cashes out" by selling his bank florins for current money in the spot market.

Recalling the notation in Appendix B, let A_t be the log of the initial Amsterdam price of a bill drawn on London and let L_{t+2} be the log of the London price of a bill on Amsterdam, two months later. Let a_t be the initial market agio expressed in decimal terms and let a_{t+4} be the market agio four months later. Investor 1's return is given as (A_t and L_{t+2} are logged bill prices as defined in Appendix B)

$$R_1 = 2.4\left(\max\left\{\frac{1}{2.406},\frac{1+a_{t+4}}{2.5}\right\}\right)\left[\exp(L_{t+2}-A_t)\right] ,$$

whereas Investor 2's return is

$$R_2 = \left(\frac{1+a_{t+4}}{1+a_t}\right)\left[\exp(L_{t+2}-A_t)\right] .$$

It follows that $R_1 > R_2$ whenever

$$\max\left\{\frac{2.4}{2.406},\frac{2.4(1+a_{t+4})}{2.5}\right\} > \left(\frac{1+a_{t+4}}{1+a_t}\right) .$$

This can occur in either of two cases. In the first case

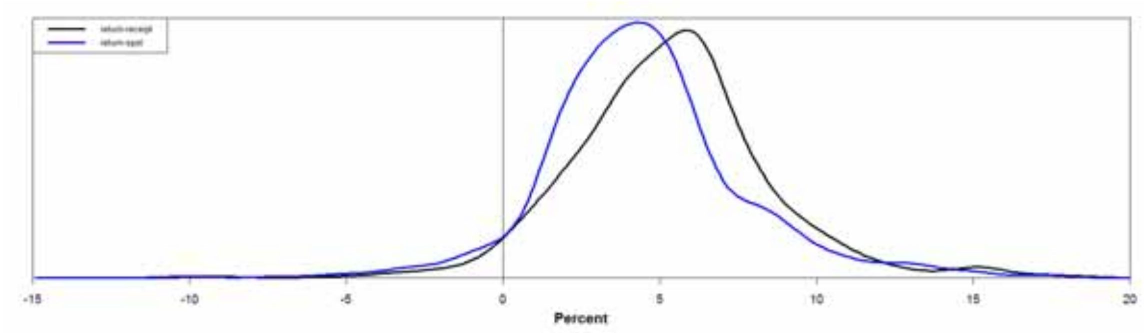
$$\frac{2.5}{2.4} = 1.04167 < 1 + a_t \ ,$$

i.e., the agio is above 4.167 percent. In the second case,

$$\frac{2.4}{2.406} = .9975 > \frac{1 + a_{t+4}}{1 + a_t} \ ,$$

i.e., the agio falls by more than .25 percent over the four-month trade. These conditions were often observed in practice. Figure C.1 plots the smoothed histograms of annualized returns (i.e., 300 × logs of) R_1 and R_2 over our sample:

Figure C.1: Empirical densities of R_1 and R_2 (annualized), 1736:1-1791:12



From the figure, we can see that the hypothetical investor funding a "carry trade" by borrowing from the Bank using ryxdaalders averages about a 90 basis points higher return than an investor who funded the same trade through the spot market (even ignoring the liquidation value of the receipt, which would have further increased this differential). In reality, it is doubtful that the Amsterdam markets allowed such a differential to persist, because its existence would have created an incentive to bid up the market price of ryxdaalders. This most likely would have been accomplished via the purchase of ryxdaalder (and similar trade coin) receipts in the daily spot market as described by L'Espine and Le Long, Adam Smith, and other contemporary observers. Unfortunately, very few records of receipt sales have been preserved, so this conjecture cannot be verified empirically.

Appendix D. The impact of bimetallic ratios on Bank operations

This Appendix considers the impact of bimetallic ratios (i.e., the relative price of gold to silver) on the Bank's operations. We lack the relevant price series to construct bimetallic ratios for Amsterdam, so we instead use contemporary data from Hamburg, whose economy was closely linked to Amsterdam during the time period we analyze. Gold and silver price data is available from Hamburg price currents (*Preis Couranten*), regular financial publications that list recent prices for a range of commodities. Copies of these were generously shared by François Velde.

The price currents report in each issue a range of prices for a reference Dutch gold coin (*dukaat*), expressed as percentage deviations from their "par" value of six Bank of Hamburg marks per *dukaat*. The implicit price per gram of gold in Hamburg can thus be expressed as

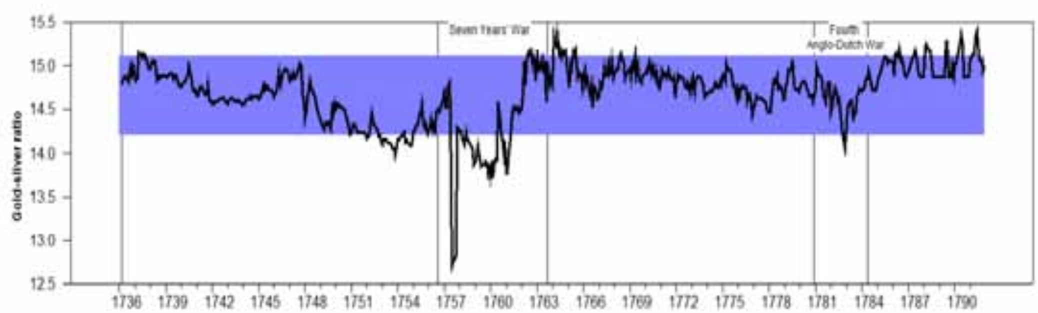
$$P_g = \left(\text{Hamburg marks per } dukaat\right)/3.4173$$

since each *dukaat* contained 3.4173 grams of gold. The price currents also report the market price of a Cologne mark of fine silver, expressed in Bank of Hamburg marks. Note that a "Cologne mark" here refers to a unit of weight, while the "Bank of Hamburg mark" refers to a currency unit. The implicit price per gram of silver in Hamburg can thus be expressed as

$$P_s = \left(\text{Bank of Hamburg marks per Cologne mark of silver}\right)/233.85$$

where the denominator gives the weight in grams of a "Cologne mark" as it was interpreted in Hamburg. Taking monthly samples of the ratio of P_G to P_S gives the following series:

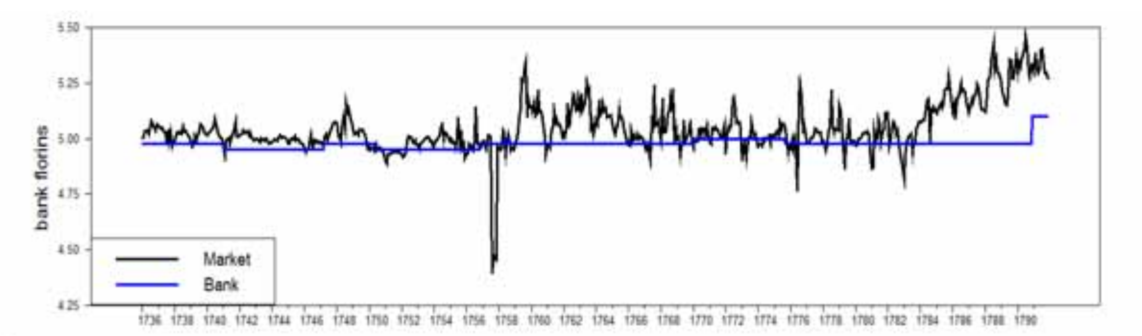
Figure D.1: Hamburg Gold-to-Silver Ratios, 1736:1-1791:12



The blue band in the figure shows arbitrage bounds derived in Nogués-Marco (2013). These are violated in favor of silver, briefly during 1753-1754 and more persistently during 1757-1760. We suspect the latter violation was induced by an extraordinary demand for silver associated with the Seven Years' War. Such violations would be expected to induce arbitrage through the coinage of gold and the simultaneous melting of silver coin. An alternative channel for arbitrage may have been to sell gold coins to the Bank of Amsterdam via the receipt window, and use the proceeds to obtain silver. The Bank's prices for trade coins tended to change only slowly and by small amounts, which could have further encouraged such arbitrage.

To gauge the impact of the price movements in Figure D.1 on the Bank, we converted the Hamburg price of gold *dukaten*, expressed in Bank of Hamburg marks per *dukaat*, into a "virtual Amsterdam market price" for gold *dukaten*. This was done using a sight Amsterdam on Hamburg exchange rate series given in Schneider, Schwarzer, and Schnelzer (1991). Because the latter series is incomplete, it was interpolated using the Hamburg on Amsterdam sight exchange rate series from the same source, in the same manner as described in Appendix B for the Amsterdam on London series. Figure D.2 displays the virtual Amsterdam market price (black) with the official price of a gold *dukaat* paid by the Bank at its receipt window, in bank florins:

Figure D.2: Amsterdam Prices of a Gold *Dukaat*, 1736:1-1791:12



The figure shows that the Bank's price for the *dukaat* incorporated a "haircut" relative to market prices until 1741, when a slight drop in the official price (from 4.975 to 4.95 florins) was enforced—probably in response to a strong inflow of *dukaten* at the receipt window. The Bank hiked its price back up to 4.975 in 1747, but again felt compelled to reduce it to 4.95 in 1750. The Bank's price stays then close to the market price until 1759.

We conclude that gold prices did create dramatic incentives, but this happened infrequently. Gold appears to have had a limited role in the long-term operations behavior that is the focus of the current paper.

Appendix E. Additional details of the VAR models

E.1 Specification

The VAR model analyzed encompasses five monthly variables:

- The market agio shown in Figure 1, recorded as percent premium.
- The annualized ex ante bill rate shown in Figure B.4, recorded in percent.
- Bank money M_L backed by loans (largely) to the East India Company and to City of Amsterdam, seasonally adjusted as described in Appendix B, and recorded in Bank florin.
- Bank money M_E backed by encumbered coin, recorded in Bank florin.
- Bank money M_U backed by unencumbered coin, recorded in Bank florin.

The VAR models are of standard form

$$y_t = \sum_{j=1}^{L} y_{t-j} B_j^R + \gamma + u_t$$

where y is the month-t observation in regime R of the 5 series given above, L is the number of lags in the VAR, the B's are 5×5 matrices, γ is a constant vector, and u is an error term. The regimes are determined by the values of

$$P_t \equiv \left\{ \text{net purchases of unencumbered coin by the Bank in month } t \right\}$$

where

$$R_t^1\left(\text{"draining regime"}\right) = I\left\{P_t < -25{,}000\right\}$$

$$R_t^2\left(\text{"adding regime"}\right) = I\left\{P_t > 25{,}000\right\}$$

$$R_t^3\left(\text{"no intervention regime"}\right) = I\left\{-25{,}000 \le P_t \le 25{,}000\right\}$$

E.2 Estimation

Based on the results of specification tests reported below, our estimation imposes constancy of parameters across regimes. Following the standard approach in the VAR literature, we specify an improper prior of form

$$f\left(\beta, \Sigma\right) \propto \left|\Sigma\right|^{-(n+1)/2}$$

where n=5, β is a vectorization of the B's and γ, and $\Sigma = Euu'$. This specification yields the well known, closed-form posterior distributions

$$\Sigma \sim \text{inverse wishart}\left[\left(NS\right)^{-1}, N-p\right]$$

$$\beta \middle| \Sigma \sim \text{normal}\left[\hat{B}, \Sigma \otimes \left(X'X\right)^{-1}\right]$$

where p is the number of explanatory variables in each equation =(5× L)+1, S and $\hat{B}$ are OLS estimates of Σ and β over the data sample, X is a vectorization of the explanatory variables in each VAR equation, and N is the number of observations in the sample. These posterior distributions are used to compute the impulse response distributions shown in Figure 6. The posterior distributions used to construct the conditional forecasts in Figures 7 and 8 make use of data only up to the beginning of the respective forecast intervals.

E.3 Stationarity

The Bayesian inference employed in this paper does not require stationarity. The largest autoregressive root of the estimated system is .993 at the posterior mean, suggesting that depending on prior weights, the system analyzed could be considered either stationary or nonstationary.

E.4 Tests for multiple regimes versus a single regime

Because it is not possible to perform Bayesian model comparisons under diffuse priors, we conducted a number of specification tests using prior distributions of the form introduced by Sims and Zha (1998). The goal of these tests was to gauge the empirical support for a VAR specification with three regimes (draining, adding, or no intervention) versus two regimes (draining or adding, no intervention) versus a specification with constant parameters over the sample.

To construct these priors, a vector of hyperparameters

$$\Lambda = \begin{bmatrix} \lambda_0 & \lambda_1 & \lambda_2 & \lambda_3 & \lambda_4 & \mu_5 & \mu_6 \end{bmatrix}$$

must be combined with scale factors from univariate autoregressions (for the details see Sims and Zha 1998, 955-960). For our first specification test, we employed a standard value for Λ. For the single-regime specification, this is

$$\Lambda_1 = \begin{bmatrix} 1 & 1 & 1 & 1 & 10 & 10 & 1 \end{bmatrix}$$

For the 2- and 3-regime specifications, the values of Λ that yield this same prior are

$$\Lambda_2 = \begin{bmatrix} 1.41421 & 0.1 & 100 & 1 & 0.01 & 7.07107 & 7.07107 \end{bmatrix}$$

$$\Lambda_3 = \begin{bmatrix} 1.73205 & 0.1 & 0.1 & 1 & 0.01 & 57.735 & .0057735 \end{bmatrix}$$

Computation of the marginal data densities from the posterior distributions implied by these priors yields the following results

Table E.1: Model comparison under Sims-Zha priors

Specification	One regime	Two regimes	Three regimes
Log MDD	-30573	-30612.1	-30610.1

The single-regime specification is thus heavily favored (with a log ratio of 37 or more) under these priors. As a robustness check, a grid search over the Sims-Zha hyperparameters was conducted for the 2- and 3-regime models, where the hyperparameters were allowed to vary by regime. The search was conducted for hyperparameter values that yielded the highest MDDs. Table E.2 reports the outcome of the search.

Table E.2: Model comparison with optimized hyperparameters

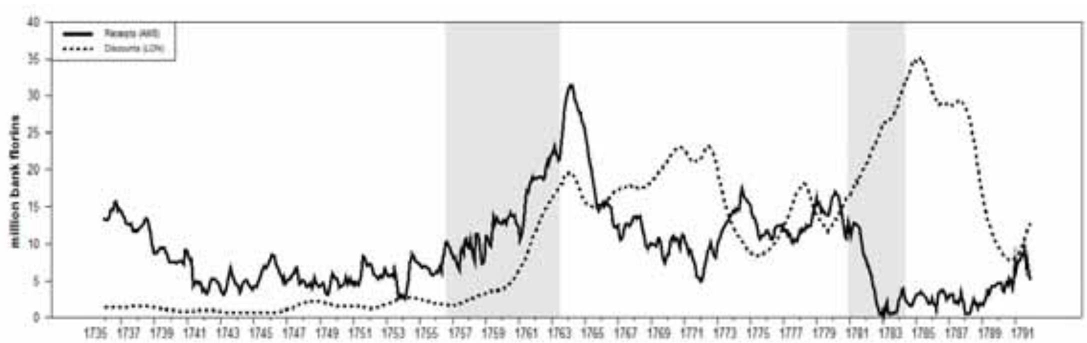
Specification	One regime	Two regimes	Three regimes
Log MDD with regime specific hyperparameters	-30573 (reference value)	-30600.4	-30597.6

Again these overwhelmingly support the one-regime specification. Our conclusion is that, of the alternatives considered, this specification best fits the data.

Appendix F: Receipts at the Bank of Amsterdam versus discounts at the Bank of England

Lovell (1957, 9) reports Bank of England credits in the form of discounts from 1729 through 1827. These data are essentially annual with some irregular intervals. To compare Bank of England's discounts to the amount of funds provided by the Bank of Amsterdam through its receipt window, we interpolated Lovell's figures to a monthly frequency using a Kalman smoothing routine and converted the monthly numbers to bank florins using London on Amsterdam sight rates from Schneider, Schwarzer, and Schnelzer (1991). The chart below compares the interpolated monthly series to the encumbered component M_E of Bank of Amsterdam money over our data sample.

Figure F.1: Bank of Amsterdam receipts vs. discounts at the Bank of England, 1736-1791



Sources: Lovell (1757), Schneider, Schwarzer, and Schnelzer (1991), Amsterdam Municipal Archives, and authors' calculation.

Shaded periods in the Figure are the Seven Years' War and Fourth Anglo Dutch War. Receipts dominate until the late 1760s. The two series are then of comparable magnitude until the collapse of the receipt system during the first years of the Fourth-Anglo Dutch War.