An Early Experiment with "Permazero"[1]

Stephen Quinn, Texas Christian University
s.quinn@tcu.edu

William Roberds, Federal Reserve Bank of Atlanta
william.roberds@atl.frb.org

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Abstract: We investigate a monetary regime with persistent, near-zero policy interest rates ("permazero"). This regime was implemented in 1683 by a prominent early central bank, the Bank of Amsterdam ("Bank"). Under this regime, the Bank's policy rate remained at one-half percent for over a century. We employ archival data to reconstruct the Bank's activities over a subsample of this regime (1736-1791) for which data is readily available. Over the majority of this sample, the data show that the Bank engaged in quantitative interventions that kept its money stock at a roughly constant level. These periods were associated with a stable value of Bank money and stable conditions in Amsterdam's financial markets. In other parts of the sample, fiscal constraints limited the Bank's ability to intervene. These periods were characterized by monetary instability, financial market disruptions, and ultimately, collapse of the Bank's policy framework.

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1 Introduction

Monetary policy today looks different than it did ten years ago. Post-crisis economic weakness has led central banks to push rates to the zero lower bound or beyond, and to hold them at historically low levels (a situation dubbed "permazero" by Bullard 2015). Proximity to the ZLB has in turn led central banks to engage in extensive quantitative operations, as an alternative channel for implementing monetary policy. Finally, the severity of the 2008 crisis has given a new impetus to macroprudential policy, and particularly to policy interactions with the formerly underappreciated "shadow banking" sector.

This situation is sometimes described as "unprecedented," but few monetary phenomena are truly lacking in historical precedents. The central bank analyzed below, in particular, offers a noteworthy case study of a (near) permazero policy regime. The institution in question, the Bank of Amsterdam (*Amsterdamsche Wisselbank*), 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 to low rates helped anchor the value of Bank's ledger money, known as the *bank florin* or *bank guilder*, a dominant currency in Europe over much of this time. The bank florin's *raison d'être* was its use as a settlement medium by Amsterdam's merchants, especially by its principal merchant banks (*wisselbankiers*). These early "shadow banks" rejected deposit-taking as a funding model in favor of market funding, and easy access to the Bank's lending facility (resembling a modern repo facility) was essential to their operations.

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, the 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 about 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

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

panic (De Jong-Keesing 1939, Schnabel and Shin 2004, Quinn and Roberds 2015). The second 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 in a world populated by shadow banks. On the positive side, skillful open market interventions by the Bank allowed it to maintain a near-zero policy rate over long periods. Inflation remained stable, and bank credit provided at this rate demonstrably supported the Amsterdam financial markets. On the negative side, the Bank's policy framework 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, 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 even today. This is the difficulty in maintaining both a low policy rate and a stable monetary value in the face of large, unforeseen shifts in market sentiment. Vulnerabilities in the Bank's policy framework remained hidden during tranquil periods, but became quickly revealed in the face of disruptive events. In such cases, a loss of monetary stability was followed by a loss of financial stability.

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 Graumann (1762), 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, 1964b, c), 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.

Unusually for its time, the Bank of Amsterdam operated under a quasi-fiat standard, but at the same time it tried to maintain a target metallic value for its money. Since the Bank maintained a constant policy interest rate and Amsterdam lacked exchange controls (Van Dillen 1964a), this situation resulted in a familiar set of stresses associated with the Mundell-Fleming trilemma (see e.g., Bordo and James 2014). The Bank's approach to managing the trilemma is perhaps most comparable to that of central banks operating during time of the classical gold standard (from about 1870 to 1914).

The two leading central banks of that era were the Bank of England and the Banque de France, institutions whose policy frameworks have been the subject of recent, detailed studies by Ugolini (2012, 2016) for England, and Bazot, Bordo, and Monnet (2016) for France. These papers show that gold-standard central banks did not always follow the well-known "rules of the game" (which called for manipulation of policy rates to counter gold flows), but instead used a variety of quantitative interventions to add or withdraw liquidity from the markets. Quantitative interventions were often employed in preference to changes in policy (i.e., discount) rates, which were viewed as disruptive to commerce. In the case of France, gold flows were routinely sterilized and policy rates changed only rarely.

As will be demonstrated below, the policy framework of the Bank of Amsterdam offers an earlier and even more extreme example of this same preference. The Bank's commitment to its policy rate was unwavering, and its preferred form of intervention, open market sales and purchases of bullion or coins, matches a tactic employed by the gold-standard central banks some 150 years later. As compared to these later institutions, however, the Bank's commitment to a metallic monetary value was relatively informal, and its interventions correspondingly less consistent.

The literature on extended low policy rates in modern economies offers a range of predictions of their potential consequences. These include the possibility of unstable inflation and subpar growth (e.g., Benhabib, Schmitt-Grohé, and Uribe 2001, Bullard 2010), unstable policy expectations followed by inflationary breakouts (Bassetto and Phelan 2015), or simply the anchoring of inflation at low levels (Cochrane 2016).

Consistent with this last scenario, inflation seems to have been generally well contained in the Dutch Republic (i.e., the Netherlands during the seventeenth and eighteenth centuries) over our sample, thanks both to the policies of the Bank and to a 1694 coinage reform (Van Zanden 2013; Polak 1998). The picture is less favorable on the output side, however, where available data suggest a stagnation or gradual decline in aggregate output, despite a mid-century peak in Bank payments activity (Van Zanden and Van Leeuwen 2017). Historians generally attribute this lackluster performance to a heavy fiscal burden and a decline in trade dominance (De Vries and Van der Woude 1997) rather than to monetary factors. Finally, our data reconstructions strongly suggest that the Bank's monetary regime was at times subject to unstable market expectations and speculative attack. In such situations, the Bank's monetary framework could then serve to amplify the potential for market disruption, as will be discussed below.

3 The Bank of Amsterdam

The Bank of Amsterdam, an agency of the City of Amsterdam, was chartered in 1609 and liquidated in 1820. The underlying institutional 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 archetypal "safe assets" due to their low credit risk, superior liquidity, and suitability as collateral (Gorton 2017). A change in a central bank's policy rate operates classically (i.e., away from the ZLB) by changing the money price of government debt, which is effectively a change in the price of a liquid, secure claim on future consumption.

Government securities did not play this "safe-asset" role in eighteenth-century Amsterdam, in part because the Dutch Republic had only fragmented and relatively illiquid markets for government debt (Gelderblom and Jonker 2011, Van Bochove 2013). Instead, this role was played principally by *trade coins*, high-denomination, high-metallic-content gold and silver coins produced in the Netherlands and elsewhere. Trade coins were liquid everywhere in Europe, and many had an exceptional value in certain markets (De Vries and Van der Woude 1997, 84). These "liquidity premia" could vary with market conditions and with the type of coin.[2] Trade coins also had a unique status 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 were the money the Bank lent at a low rate.

In a modern context, a central bank's policies may impact the economy through their 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 liquidity, however, as a provider of repo credit to the Amsterdam bill market.

Bank accounts were valuable because they were the legal means to discharge bills of exchange payable in Amsterdam.[3] 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

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[2] The existence of these premia meant that trade coins (both foreign and domestic) in Amsterdam generally had a positive rate of return, although this return varied over time and could often only be realized in distant markets. As a result, many trade coins were more used in international transactions than in the Dutch domestic economy. A modern example of an asset with comparable cross-border functionality would be U.S. Treasury securities, whose value as a safe asset is recognized worldwide and at times may be higher abroad than within the U.S.

[3] The Bank's 1609 charter gave it a legal monopoly of bill settlement within Amsterdam. This restriction was apparently relaxed somewhat over time, so that certain types of bills (e.g., those drawn by Swedish merchants) were settled outside the Bank. The literature is an agreement, however, that settlement in Bank money predominated throughout our period of interest.

"matched-book" approach to leverage created an early example of "shadow banking." Regulation of this market was limited to market discipline ("honor"). However, the use of bank money as a settlement asset for bills allowed the Bank to exert a certain degree of control over the bill market and its participants.

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 3400 tons of silver, or 1.5 to 2 times annual Dutch GDP (De Vries and Van der Woude 1997, 702) or 2.5 times the GDP of the province of Holland (Van Zanden and Van Leeuwen 2017). Since bills could circulate via endorsement, and some bills settled outside the Bank, the true amount of turnover in the Amsterdam bill market was undoubtedly higher than these figures suggest. Much of this payment activity supported the movement of goods and capital throughout Europe, reflecting the "vehicle currency" status of the bank florin. As a standard of comparison, an analogous ratio for the Federal Reserve (annual value of Fedwire payments/ U.S. GDP) comes in at 2.65 at the peak of the Bretton-Woods era (in 1955; see 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, 1964b; Dehing 2012; Quinn and Roberts 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.[4] 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 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 or her 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.

Take for example a transaction: in February 1737, 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.[5]

Coins, such as Mr. Vos' in this example, that were held in the Bank's vault with 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.

<Table 2 follows next page.>

[4] 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).

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

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.

For silver trade coins that constituted the bulk of the Bank's receipt business, the "strike price" of a receipt was generally 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-fourth percent. [8] Receipts could be rolled over at the same cost as for redemption, and were fully negotiable as bearer instruments.[9]

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

[8] In 1765, the rate on three-guilder coins increased from one-eighth to one-fourth percent. 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.

[9] 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.

policy interest rate.[10] 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 the quality of the collateral involved (trade coins) was such that the issue of receipts entailed little risk to the Bank. This rate was substantially lower than contemporary rates on relatively secure but uncollateralized instruments, such as bills of exchange (with a mean return of around 4 percent; see Appendix B) or the debt of the province of Holland (about 2.5 percent, see 'T Hart 1997).

The repo-like credit available through the receipt window was a key advantage of Amsterdam over other contemporary financial markets. Essentially, the existence of this facility (combined with an absence of capital controls) meant that trade coins could be more liquid in Amsterdam than elsewhere, since coins under receipt could be utilized for transactions in the Amsterdam market, pending their shipment to other markets where their highest value could be realized.[11] Johann Philipp Graumann (1762, 137), an experienced trader in coins and bills of exchange, described the function of the receipt facility as follows (our translation):

> How advantageous this lending [facility] must be for the merchant community, can be seen from the fact that with this facility, the merchant can put into motion and utilize all the monies [i.e., trade coins] that accrue to him. Otherwise he would have to allow the same foreign coins to sit unused, and at going [bill] interest rates lose more money than he would pay for borrowing [at the receipt window]. By this means the [deposited] money is effectively doubled, or twice put at the disposal of commerce, since the merchant can make use of practically all of the capital that he has placed in the bank. In addition, he remains master of this money, and by repayment of the sum advanced, is authorized to either withdraw it himself, or sell it to others.

Despite the clear parallels, there are two noteworthy differences between the receipt system and modern central bank repos. First, 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. The quantity of credit generated through this standing facility was 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. Second, there are instances in our dataset where market participants allowed receipts to expire. 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.

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[10] By structuring the second leg of its "repos" as an option, the Bank was apparently able to replicate the key advantage of modern repo contracts, i.e., exemption from bankruptcy stay. To our knowledge, private parties could not offer equivalent contracts with coins as collateral.

[11] On the other hand, the Bank did not provide direct support of the bill market through a discount window, as did the contemporary Bank of England. Credit granted through the receipt facility matches or exceeds Bank of England discounts, however, until 1764 (see Appendix F).

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.[12] 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 "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 (outright) open market transactions. No receipts were granted for these 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.

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

3.1.3 Loans

The Bank's charter excluded it from making loans—other than granting credit through the receipt window, which was not thought of as lending. In practice, however, the Bank routinely engaged in lending activity. 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 and 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.[13]

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.[14] The loan chamber did reliably repay the bank with 2 percent

[13] Our use of the term "equity" (for assets less liabilities) follows modern central bank accounting terminology (see Archer and Moser-Boehm 2013). Negative equity is relatively common for central banks. A more valid indicator of a central bank's health is usually given by its *net worth*, which is its equity augmented by the 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.

[14] 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.

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

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

where

$$M_E \equiv E \;,$$

$$M_U \equiv U \;,$$

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

In words, the first component M_E represents the quantity of Bank money backed by coins under receipt, which is equal to (as an identity) 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 equal to (again, identically) 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 $-\varepsilon$.[15]

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 the Bank may have lacked formal legal authority to conduct its open market operations. The extent of these transactions, like the other details of the Bank's balance

[15] 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.

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 coins under receipt, 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* 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 could then be seized by the City. Recent theoretical studies (Sims 2004, 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.[16]

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.[17] Acquiring *ryxdaalder* coins and then depositing them created an implicit agio of $a_{ryxdaalder} = 100\left(\left(2.5/2.4\right)-1\right) = 4.167\%$. Each trade coin had a slightly different implicit agio 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 complementary 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

[16] The market agio was routinely reported in the financial press and Amsterdam merchants would have been well informed about its current value. An informal agio target 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.

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

the market agio.[18] As with other specie-flow examples such as the classical gold standard, these incentives can prove weaker than the other reasons people exchange money (e.g., liquidity values and expectations of future price movements).

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 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 of this asymmetry, 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 (i.e., market participants' migration to and away from the receipt window) complicates the response to open market operations.

3.3.1 Vulnerabilities

Sims (2004) predicts that central banks without clear fiscal backing will always face a stark choice of either 1) accumulating politically unsustainable levels of reserve assets, or 2) transferring such reserves to a fiscal authority and leaving themselves open to speculative attack. By routinely transferring much of its unencumbered coin to the City, the Bank in effect chose

[18] I.e., the Bank would be purchasing coin via the receipt window at a higher price than the market, while simultaneously selling insurance against a market reversal. 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.

the second option. Consistent with Sims' prediction, the resulting vulnerability was manifested in two forms of speculative pressure on the Bank.

The first type of pressure could result when pessimistic receipt holders (including people who had purchased receipts on the open market) simply redeemed 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 Bank was subject to a second and subtler type of speculative pressure during the Seven Years' War (1756-1763). At that time, market participants apparently retained faith that the Bank would honor receipt obligations, but participants also had a negative outlook for the bank florin (i.e., expectation that the value of coin might sharply appreciate). They found it attractive to sell trade coins to the Bank through the receipt window despite a market agio below its customary range. The proceeds could then be used to purchase foreign currency forward (bills drawn on foreign markets), as a hedge against further florin depreciation.

Under this scenario, receipts granted by the Bank would then have functioned as put options on the domestic value of the bank florin (call options on trade coin), ensuring that the receipt window remained popular even though the market agio remained low through the war. The resulting inflow of coin through the receipt window increased the stock of Bank money, increasing pressure on the bank florin. Volatility of the agio also increased at this time (see Appendix B), which would have worked to increase receipts' option value. To defend against the weakening of the florin in foreign and domestic markets, the Bank's policy framework did not allow for an increase in its policy rate (i.e., a hike in receipt redemption fees). Instead, the Bank could sell unencumbered metal into the market, but such activity could not always be sustained.[19]

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

[19] The markets' 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).

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.[20]

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 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, or 1,336 transactions per year on average.[21]

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.[22] 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

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

[21] 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 Roberts 2016).

[22] 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.

of the two sets, we identify an offsetting change in the balance sheet for each change in monetary liabilities.[23] 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 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 sterilized 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

[23] 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 Roberts 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.

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.

<Figure 5 here.>

Figure 5 offers another view of the stresses faced by the Bank, by aggregating flows of metallic collateral (virtually all as trade coin) in and out of the receipt window to an annual frequency. The figure shows that inflows increase in a spectacular fashion during the Seven Years' War, peaking in 1758 at nearly 24 million florins, of which 9 million are due to gold coins and 15 million to silver. These amounts translate to about 6.3 tons of gold and 150 tons of silver, quantities whose significance becomes apparent when they are compared to contemporary annual world production of these metals: about 24.6 tons of gold and 533 tons of silver (Soetbeer 1885, 7). In other words, amounts equal to at least one quarter of the world's production of these metals found their way into the Bank at this time, in search of the liquidity available through the receipt facility.[24] Up through 1760, metal inflows are partially offset by large outflows. After 1760, gold flows recede, as do silver outflows. The elevated movement of silver into the Bank continues through 1763, however, eventually creating more credit capacity than the market could handle.

The purpose of these outsized coin flows is not recorded in the Bank archives, but undoubtedly the majority went to support international finance. Many of the trade coins involved were rarely used in local transactions, and the wartime domestic economy in Amsterdam was moribund (De Jong Keesing 1939, Chapter 1).

5 Econometrics

A challenging aspect of the data presented in the previous section is that the Bank's records do not record intent. For example, the Bank collected fees and interest through the destruction of liabilities. The City, however, preferred to collect this profit as a payment in coin instead of

[24] The path of such metals from mining areas to the Bank of Amsterdam could be fairly direct, taking the form of Spanish coins sold to the Bank through the receipt facility, or bars that were processed by Dutch mints and subsequently sold to the Bank as trade coin (Van Dillen 1964a). The actual flow of metal through Amsterdam would have included additional quantities traded in the daily spot market, transactions which are more difficult to track through the Bank's accounts.

in balances. As a result, the Bank intermittently purchased 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 was never assigned to a specific purchase. Neither were other possible motivations such as sterilization. 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 effects of the fees it charged for receipts, or sales of small amounts of precious metals to supply jewelers and similar users. Instead, all such transactions appear as additions to or drainage from M_U. Given these ambiguities, it is difficult to precisely identify the Bank's policy actions over the sample. In lieu of such an identification, this section presents several less formal econometric exercises, in order to provide some statistical measurement of the motivations and effects of the Bank's open market interventions.

As a first step, 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.

5.1 What motivated interventions?

Why did the Bank of Amsterdam intervene? In particular, did the Bank actively seek to stabilize the price of Bank money? To investigate these questions, we 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.[25] 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 for the details). 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 below.

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 subsample, 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, consistent with the idea that the Bank tried to shore up the value of its money in such situations. Absent the interaction with the metal stock, however, a low agio is estimated to reduce the chance of both draining and adding operations. In other words, countering the effects of a low agio required a sufficient stock of unencumbered coin. On the other hand, a high agio increases the chances the Bank will add liquidity. Such operations would have allowed the Bank to exert downward pressure on the agio, and to accumulate coin for future interventions or seigniorage payouts.

<Table 4 follows, next page.>

[25] 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

Current month's regime	Explanatory variable	Next month's regime: 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.

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.

Figure 6 plots the evolution of the 1-month-ahead transition probabilities implied by the logit models (at the posterior mean coefficients).

<Figure 6 here.>

The figure hints 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 to keep the agio close to target.

5.2 VAR approach

A second 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. 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 policy actions, 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. Hence results from a single VAR are reported.[26]

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 7 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.

<Figure 7 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.[27] A similar pattern occurs with

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

[27] 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

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.

5.3 Counterfactual scenarios

For our final econometric exercise, we analyzed counterfactual scenarios over two policy-failure intervals, the purpose being to estimate the scale of consequences following from the Bank's lack of collateral at moments of systemic pressure. 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.[28] 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.[29] The conditional forecast distributions are plotted in Figure 8, along with the implied distribution for total Bank money.

<Figure 8 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.[30] 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

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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 detect specie-flow effects.

[28] Another market dynamic begins in August 1763, with the outbreak of a financial panic in Amsterdam.

[29] 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.

[30] Median forecasts are shown in Figure 8 rather than means, due to skewness of the conditional forecast distributions.

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 9 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.[31] The counterfactual scenario is constructed as a conditional forecast beginning in 1783:7 that constrains deposits to match their yearend 1786 level.

<Figure 9 here.>

The forecasts in Figure 9 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 9 project a 2.5 million florin reduction in Bank money backed by loans M_L. At this time, however, 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 9 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 credit at the receipt window (Figure 7), which helped control the liquidity available to the Amsterdam bill market. This approach to intervention met its limits during the Seven Years' War, when the Bank lacked adequate unencumbered metal to respond to large receipt inflows (Figure 8). The Bank became less likely to engage in draining

[31] Our scenario stops well before 1788, when trade coins begin to come back into the Bank due to political uncertainty.

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 9).

Less clear from the analysis are the weights that the Bank attached to various policy goals. Over most of the sample, the Bank's actions were consistent with stability of the agio and supportive of liquidity in Amsterdam's financial markets. Our twenty-first century interpretation of these operations is necessarily anachronistic, however. Lacking official policy statements, we cannot dismiss the possibility that the Bank's managers were guided more by profit-taking rather than by altruism. 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 money stock created through the Bank of Amsterdam's lending facility (i.e., through its receipt window) was intensively managed by means of the Bank's open market operations.

The receipt window brought with it advantages and disadvantages. On the one hand, its repo-like functionality and its low implicit interest rate encouraged efficient use of trade coins as collateral, thereby increasing the demand for Bank money and deepening the capacity of Amsterdam's financial markets. 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. The Bank's open market operations counterbalanced the resulting fluctuations in the stock of Bank money, but these operations were hampered by the Bank's commitment to its low policy rate, its limited levels of owned assets, and its incomplete fiscal support. The theoretical literature predicts that such conditions can give rise to speculative pressures, and the data in our sample are consistent with this prediction.

A low interest rate policy was thus both a foundation of the Bank's policy framework 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 extent 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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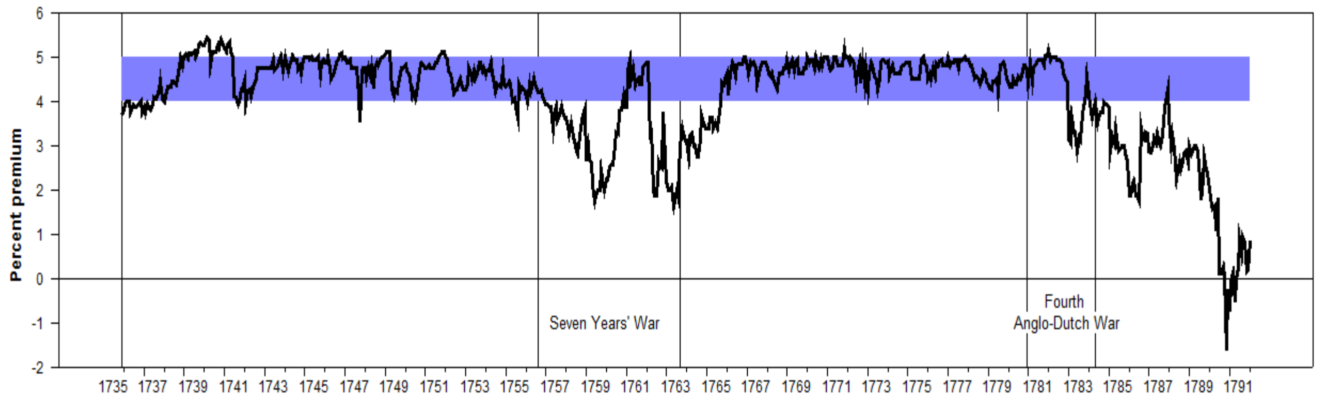
Figure 1: Market agio, 1735:12-1792:1

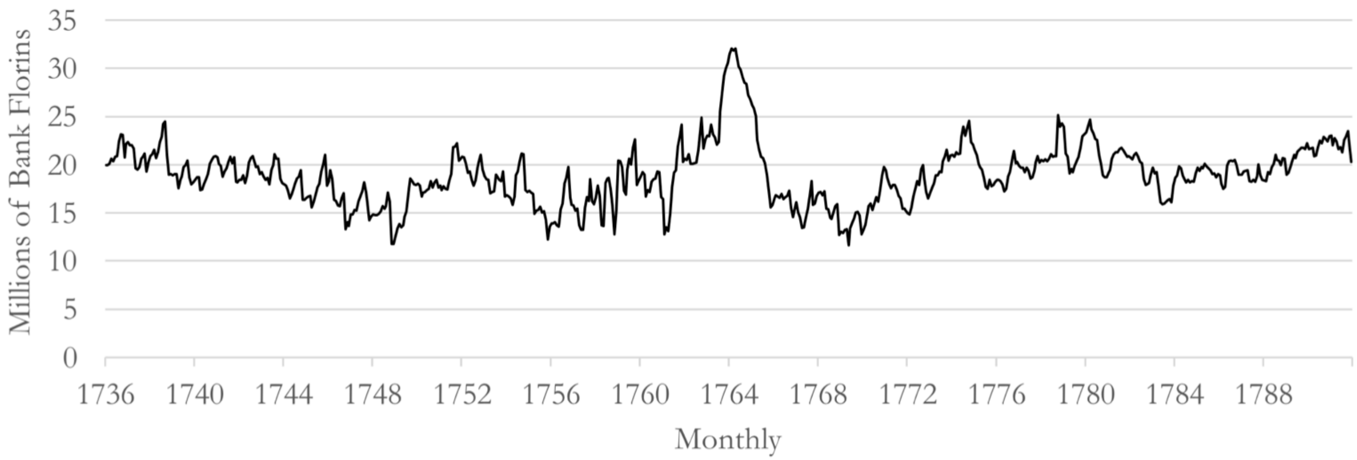
(Percent premium bank florin over current florin)



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 data sample to reflect the date conventions in the archival data.

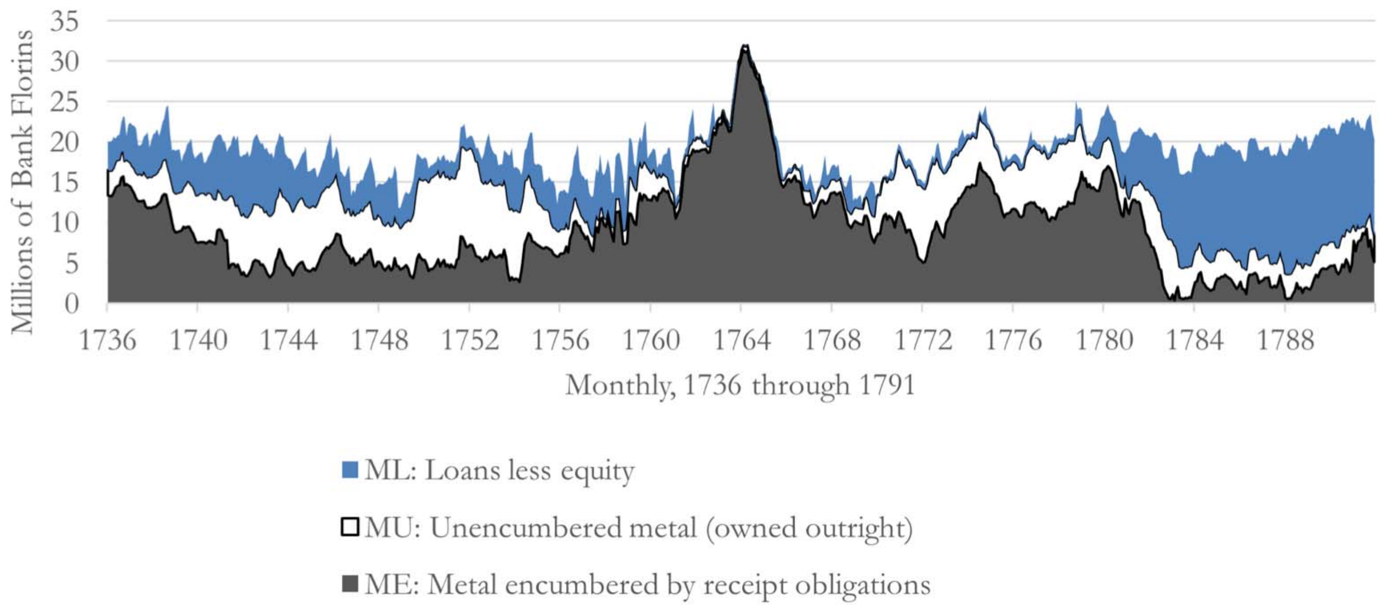
Sources: Gillard (2004) and Schneider, Schwarzer, and Schnelzer (1991).

Figure 2: Monetary liabilities from 1736 through 1791



Sources: Amsterdam Municipal Archives and authors' calculations.

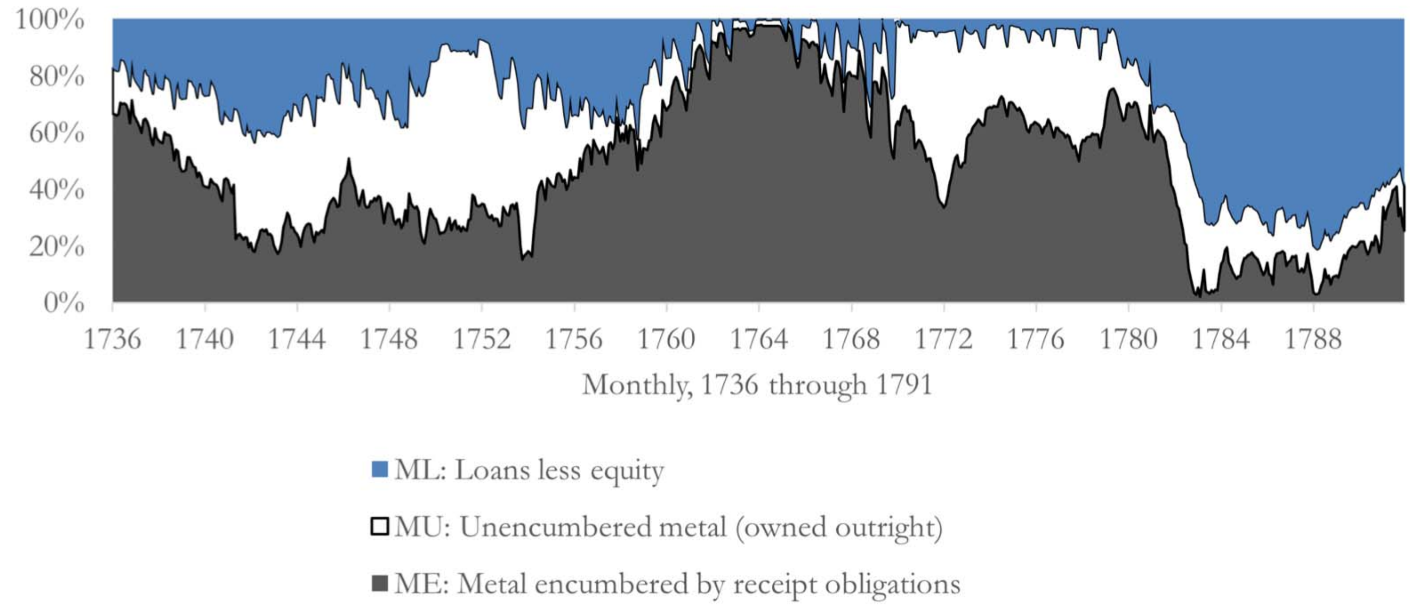
Figure 3: Backing of monetary liabilities



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

Sources: Amsterdam Municipal Archives and authors' calculations.

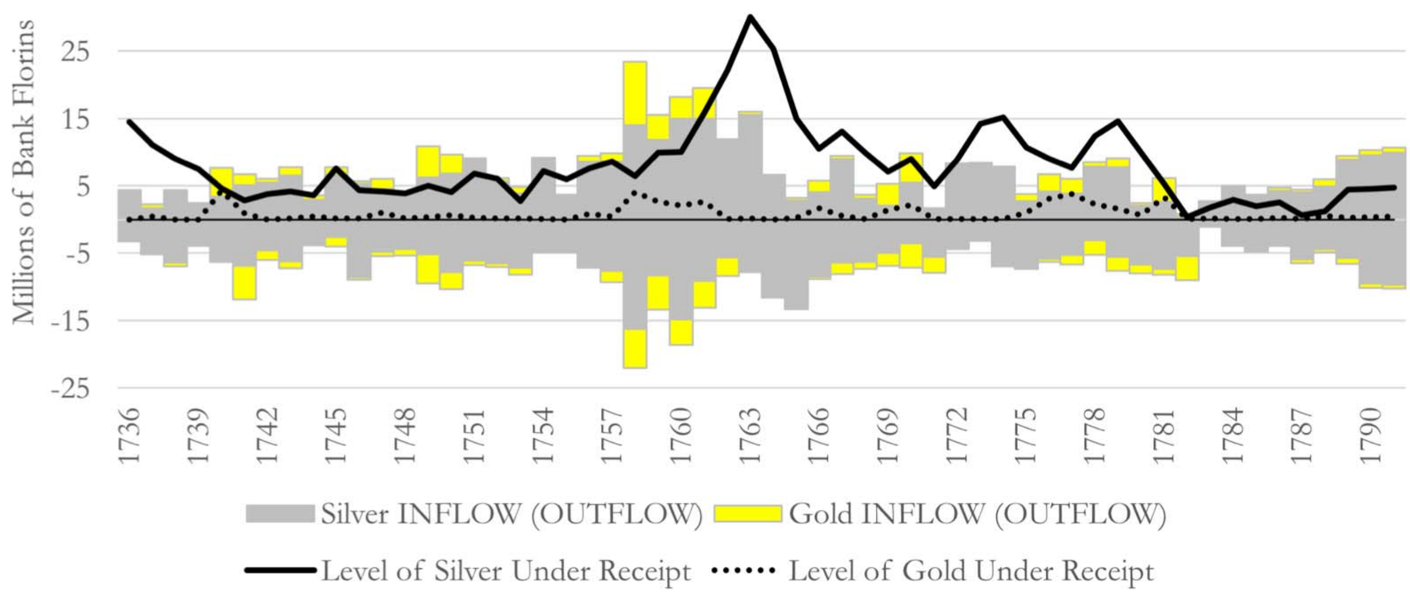
Figure 4: Share of monetary liabilities by backing



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

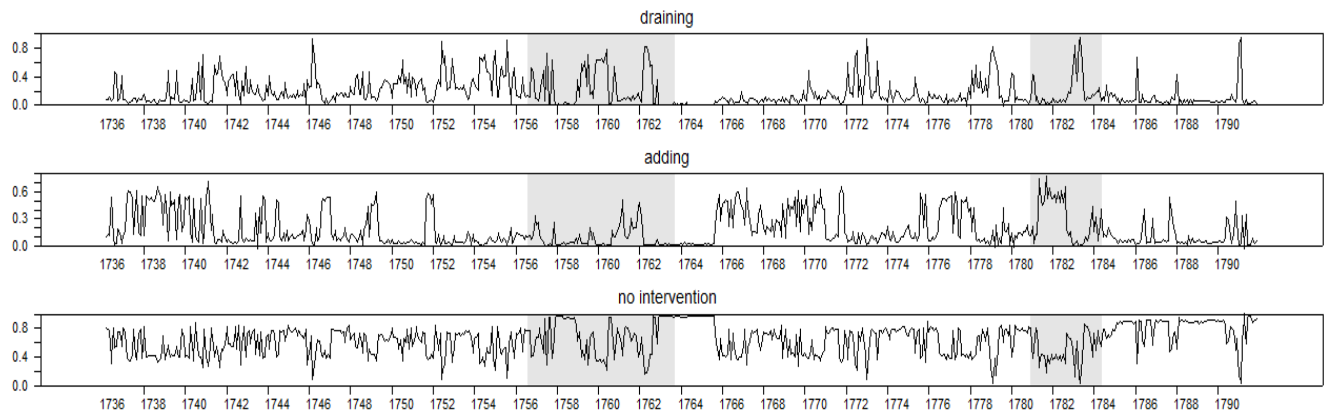
Sources: Amsterdam Municipal Archives and authors' calculations.

Figure 5: Annual Churn by Metal Unter Receipt



Sources: Amsterdam Municipal Archives and authors' calculations.

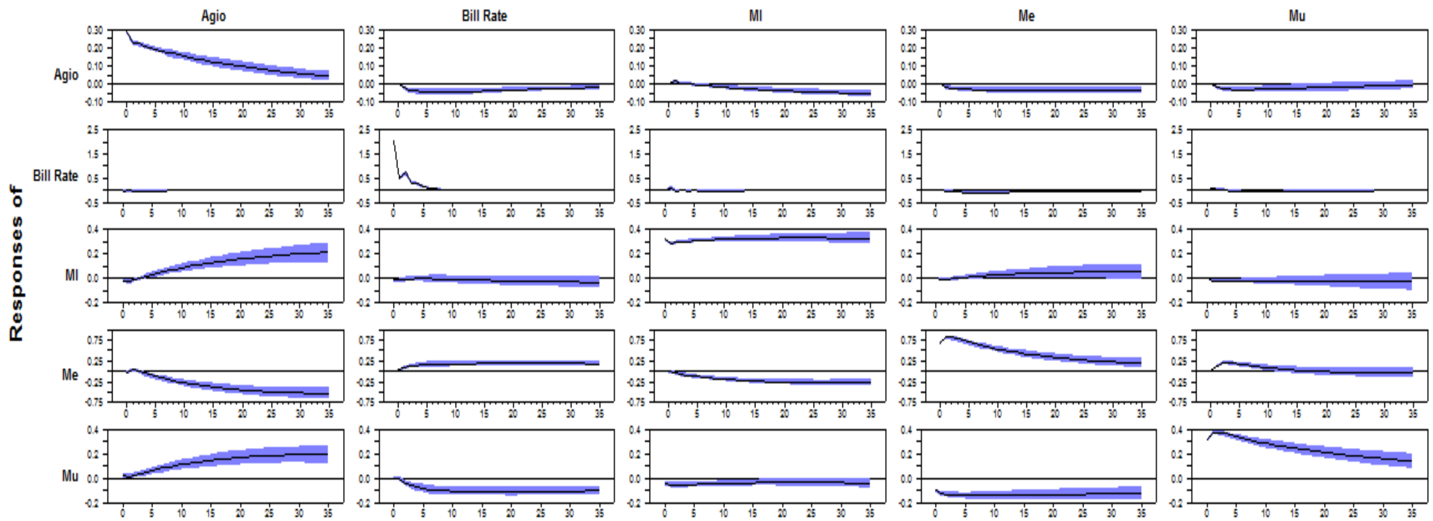
Figure 6: One-month ahead transition probabilities, 1735:12-1791:12



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

Source: authors' calculations.

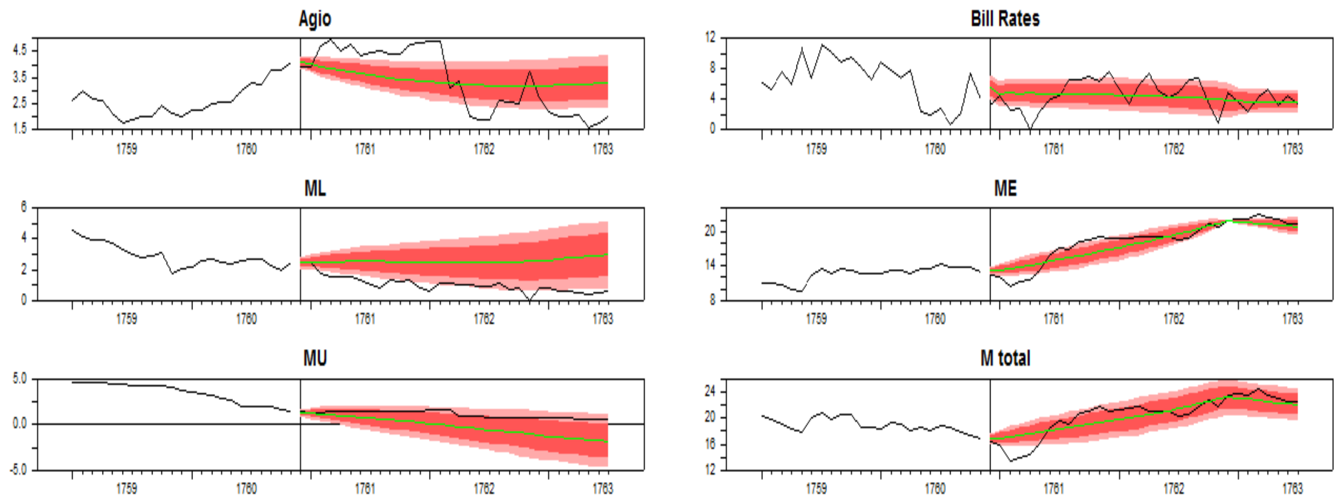
Figure 7: Impulse responses



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.

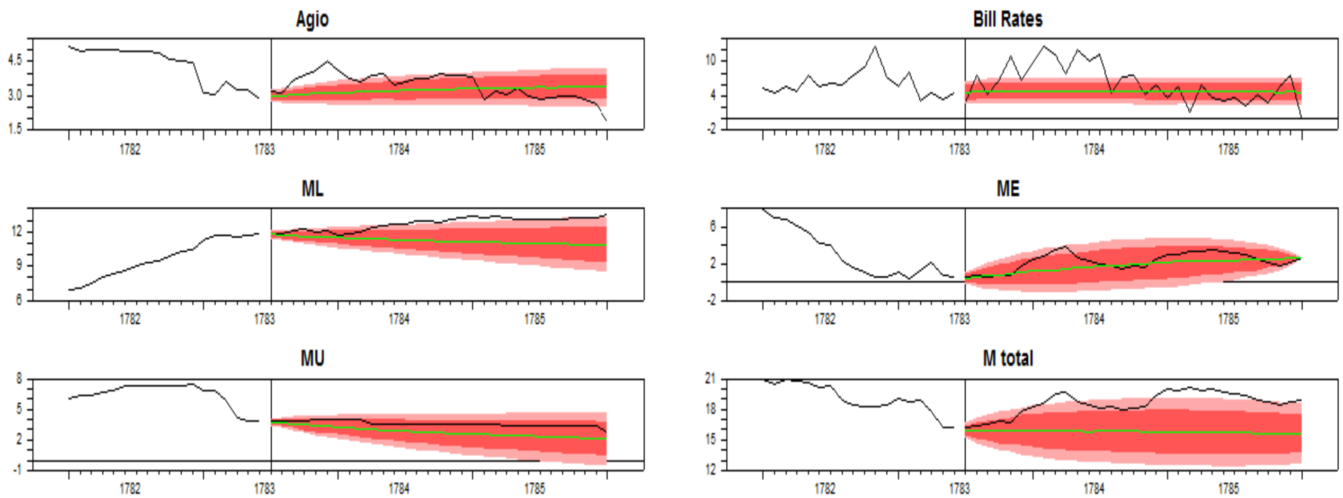
Figure 8: Conditional forecasts versus actual series, 1760:12-1763:7



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 9: 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

(not for publication)

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 Siviliaanen (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 ($1/40^{th}$). Examination of *staten drie gulden* transactions from 1761 through 1764 (there were none in 1746), suggests the Bank usually rounded to the nearest $1/40^{th}$. 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.

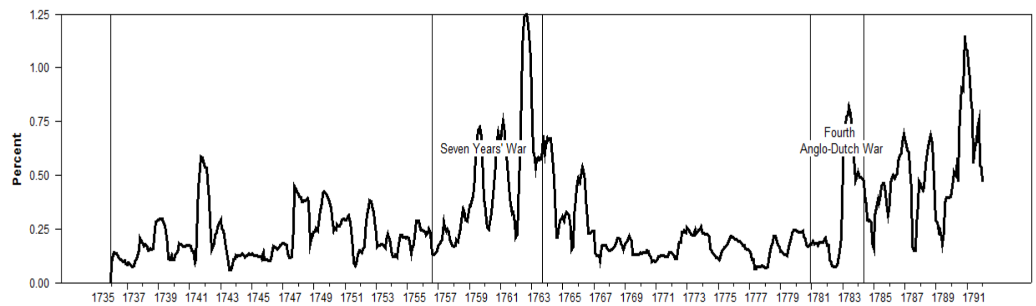
Appendix B: Additional details of data series

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

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

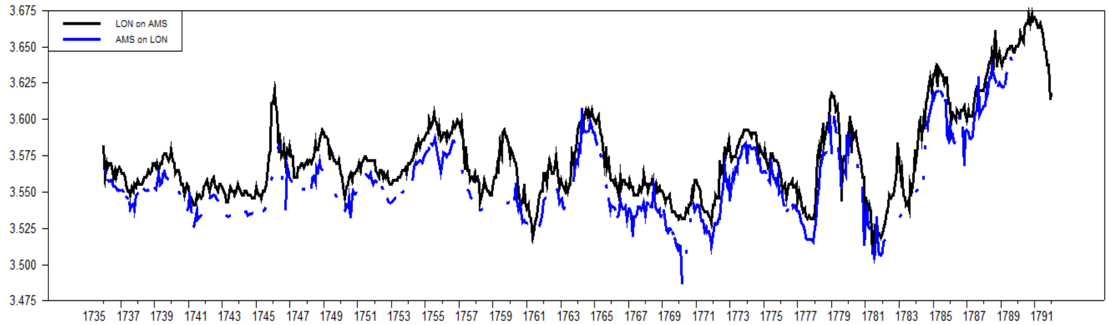
where L_{t+2} is the log of the 2-month ahead London price of a 2-month bill drawn on Amsterdam, and A_t is the log of the current month Amsterdam price of a bill drawn on London. The literature traditionally calculates the ex ante bill rate as

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

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

$$A_t = x_t \ ,$$

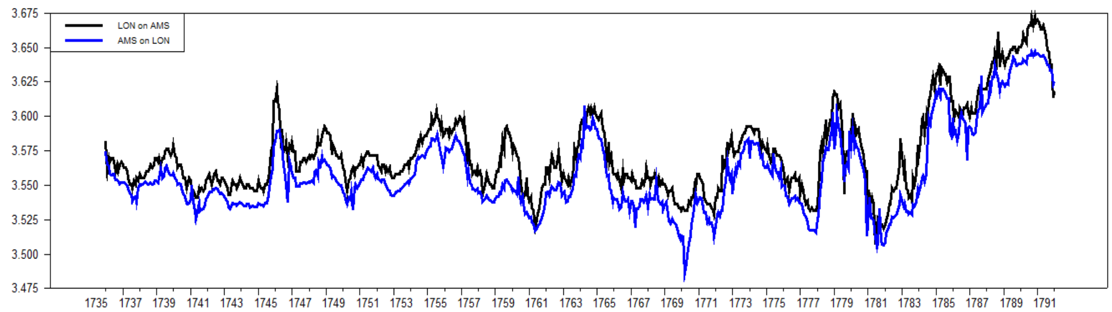
and the (demeaned) London on Amsterdam bill price similarly follows

$$L_t = x_t + z_t \ .$$

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

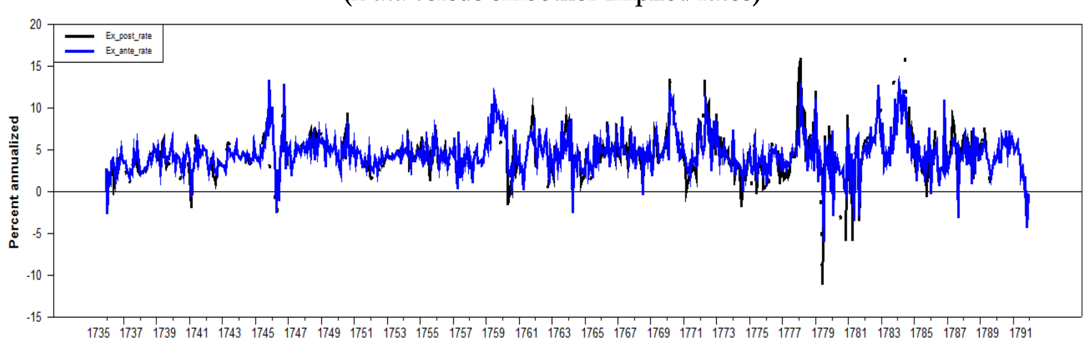


With the smoothed series in hand, we then calculated ex ante bill rates $\hat{r}_t$ as

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

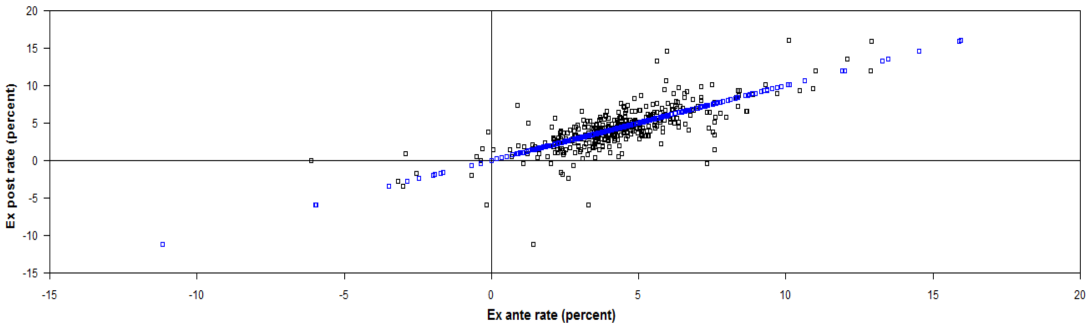
where $\widehat{A_t}$ is the smoothed value of the log of the Amsterdam on London bill price, and $\hat{L}_{t+2}$ is the 2-month ahead projection of the log price of London bills on Amsterdam. Our method thus follows the traditional approach in that each bill price is approximated as a random walk. What 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)

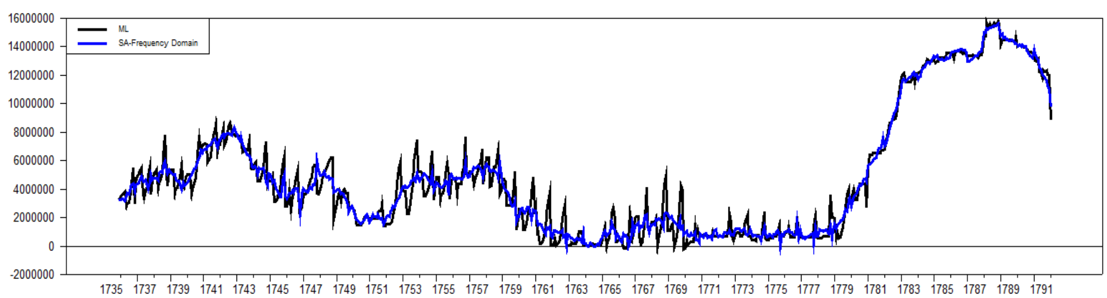


B.3 Seasonal adjustment of the M_L (money backed by loans) series

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 M_L 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 M_L 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.

[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

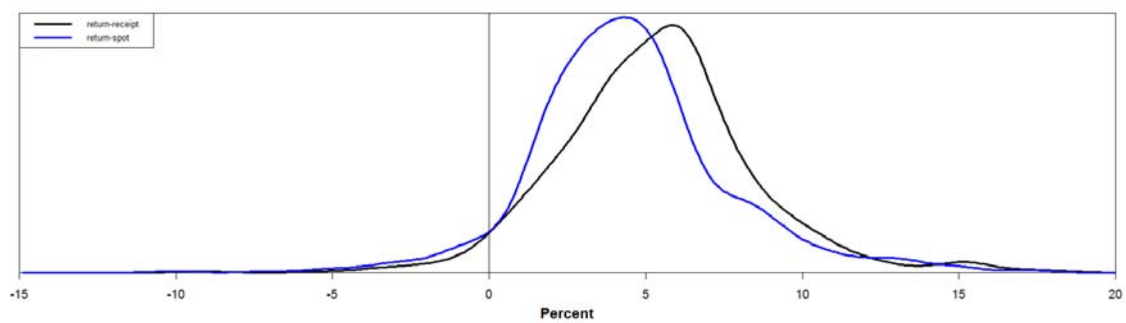
$$\frac{2.5}{2.4} = 1.04167 < 1 + a_t \ ,$$

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

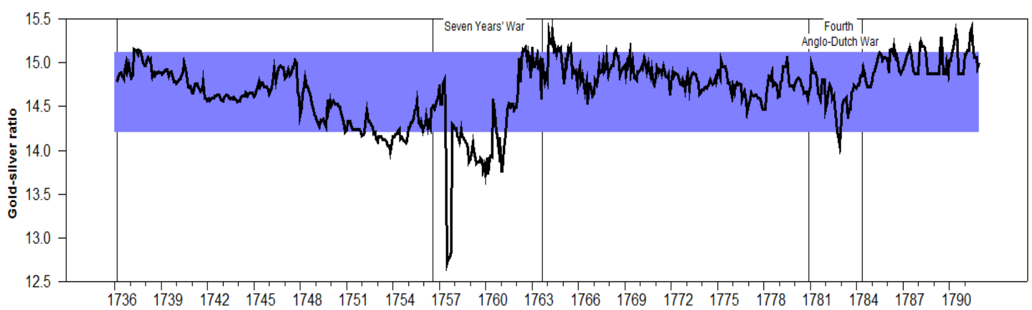
$$P_g = \left(\text{Hamburg marks per } \textit{dukaat}\right)/3.4173$$

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:

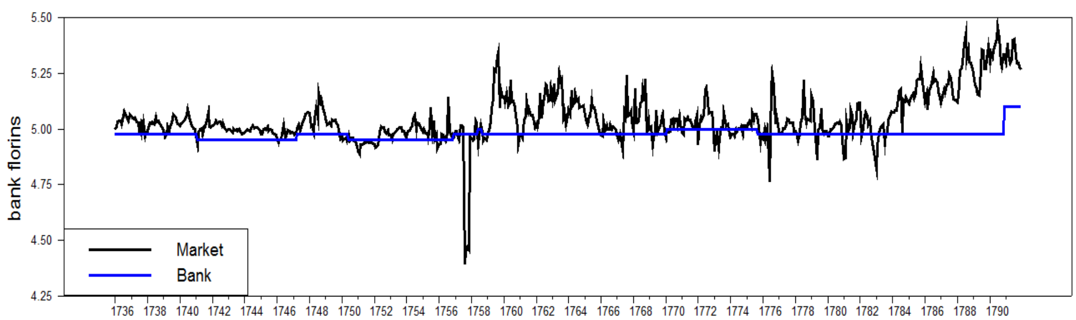
Figure D.1: Hamburg Gold-to-Silver Ratios, 1736:1-1791:12



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

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

where

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

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

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

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

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

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

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

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

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 coefficient estimates, 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

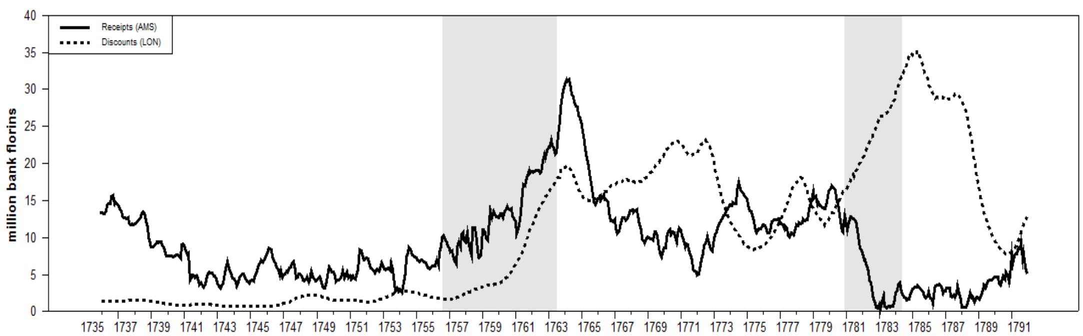
Specification	One regime	Two regimes	Three regimes
Log MDD with regime specific hyperparameters	-30573 (reference value)	-30600.4	-30597.6

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.