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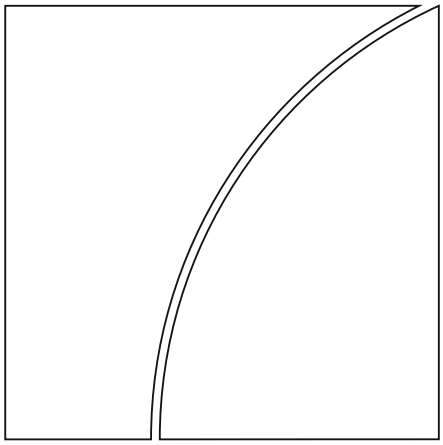

BIS Working Papers

No 698

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Monetary and Economic Department

February 2018

JEL classification: E42, E58, N13.

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This publication is available on the BIS website (www.bis.org).

ISSN 1020-0959 (print)
ISSN 1682-7678 (online)

Money and trust: lessons from the 1620s for money in the digital age*

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February 5, 2018

Abstract

Money is a social convention where one party accepts it as payment in the expectation that others will do so too. Over the ages, various forms of private money have come and gone, giving way to central bank money. The reasons for the resilience of central bank money are of particular interest given current debates about cryptocurrencies and how far they will supplant central bank money. We draw lessons from the role of public deposit banks in the 1600s, which quelled the hyperinflation in Europe during the Thirty Years War (1618-1648). As the precursors of modern central banks, public deposit banks established trust in monetary exchange by making the value of money common knowledge.

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*An earlier version of this paper was circulated under the title "The *Kipper- und Wipperzeit* and the foundation of public deposit banks". We thank Morten Bech, Vincent Bignon, Forrest Capie, Stijn Claessens, Piet Clement, Marc Flandreau, Charles Goodhart, Timothy Guinnane, Hendrik Hakenes, Stephen Morris, Larry Neal, Stephen Quinn, Will Roberds and Nathan Sussman for comments. The views expressed here are those of the authors and not necessarily those of the Bank for International Settlements.

1 Introduction

Money as a means of exchange is a social convention. One party accepts money as payment in the expectation that others will do so. This bare definition does not leave much room for the special role of central banks. Over the ages, various forms of private money have come and gone. Some have lasted longer than others, but they have given way to central bank money. The reasons for this resilience of central bank money are of particular interest given current debates about cryptocurrencies and how far they will supplant central bank money.

We draw lessons on the nature of money by examining the role of public deposit banks established in the early 1600s, which quelled the hyperinflation in Europe during the Thirty Years War (1618-1648). The Bank of Amsterdam, famously discussed at length in Adam Smith's (1776) *Wealth of Nations,* is perhaps the best known of these public deposit banks. We argue that the public deposit banks were early precursors of modern central banks, and that they were able to establish trust in monetary exchange by making the value of money common knowledge. The lessons resonate through the intervening years to current debates about cryptocurrencies and the nature of money.

The Thirty Years War involving the small German states and neighbouring regional powers was associated with one of the most severe economic crises ever recorded, with rampant hyperinflation and the breakdown of trade and economic activity. The crisis became known as the *Kipper- und Wipperzeit* (the clipping and culling times), after the practice of clipping coins and sorting good coins from bad.

Episodes of currency debasement have occurred throughout history, but the Kipper- und Wipperzeit stands out for two reasons. The first is the severity of the crisis and its rapid regional spread. Currency debasement proceeded at such a pace that the public authorities quickly lost control of the downward spiral.

The second reason why the Kipper- und Wipperzeit stands out is the manner in which debasement was brought under control. A key step was the standardisation of wholesale payments through public deposit banks. The Bank of Amsterdam was the first, established in 1609. The German deposit banks, the Bank of Hamburg (founded in 1619) and the Banco Publico of Nuremberg (1621), were established at the height of the crisis.

Public deposit banks share with modern central banks the feature that their deposits served as a platform for a cashless payment system in which transactions between account holders were settled by transfers from one account to another. However, unlike with modern central banks, new deposits

could be created only by holders surrendering gold and silver coins. In this sense, bank money reflected the value of underlying coins, but the convenience of bank money for settlement of transactions meant that bank money traded at a premium (*agio*) to the underlying coins, with the premium reflecting the value to account holders of the convenience of bank money for settlement. The agio was substantial. Adam Smith reports that the typical agio in Amsterdam was between 2 and 5 percent, and much higher elsewhere.[1] Quinn and Roberds (2007, 2014) provide a detailed picture of the operation of the Bank of Amsterdam and its subsequent development as an early precursor of modern central banks.

In seeing the origin of central bank money in terms of these early public deposit banks, our view (and that of Quinn and Roberds) differs from the conventional view, as argued for instance by Charles Goodhart (1988), that central banks were established primarily as a way for the state to finance wars. The ability to lend is typically seen as the crucial characteristic of central banks. In contrast, the public deposit banks of the early 17th century initially were not designed to engage in lending; their main function was to provide a payment and clearing system.

In practice, however, the deposit banks also engaged in lending, although to differing degrees. One example was the Banco Publico of Nuremberg, which engaged in substantial lending to the City of Nuremberg, contrary to its charter. Perhaps for this reason, this bank was far less successful than the Banks of Amsterdam and Hamburg (Kindleberger (1991, 1999)). It ended up with a meagre deposit base and never managed to establish itself as a major giro bank - a bank whose deposits serve as a means of payment. Besides preserving the soundness of the currency, the Banks of Amsterdam and Hamburg played crucial roles in promoting the institutions that underpin financial innovation and economic development through settlement of financial claims and bills of exchange.[2]

We argue that the source of the success of public deposit banks was their role in instilling *common knowledge* in monetary transactions by establishing a platform for standardised settlement of transactions, both for goods and for financial instruments.

Common knowledge refers to not only the fact that everyone knows, but also that this knowledge is transparent to all concerned. The philosopher David Lewis (1969) provided a celebrated analysis of why common knowledge is key to social conventions, and common knowledge is also the cornerstone

[1] Wealth of Nations (1776), p. 421 of 1991 printing.

[2] See Schnabel and Shin (2004) for an account of the role of bills of exchange and the crisis of 1763.

of the analysis of equilibrium in economics and game theory.

The importance of common knowledge is especially relevant in monetary economics in the age of distributed ledger technology (DLT) and Bitcoin, as one interpretation of money is as a score-keeping device on the history of past transactions. The analysis of money as a score-keeping device was given emphasis by the paper by Kocherlakota (1998), whose title is "Money is memory". In the setting of Kocherlakota's analysis, a costless, publicly accessible record of all past transactions that is common knowledge can achieve the allocation with money, and sometimes more. On the other hand, Bhaskar (1998) and Bhaskar, Mailath and Morris (2012) show that such results are not robust to small departures from the common knowledge of infinite histories of transactions. This is so even if the record-keeping device is costless. The current debates about the role of DLT and whether it will displace central bank money thus crucially depend on how important common knowledge is for monetary exchange and how well DLT can recreate the pre-conditions for common knowledge. We return to this issue below.

Commodity money is vulnerable to problems of informational asymmetries and adverse selection, especially in times of frequent devaluations. We present a theoretical model in the spirit of Shin (1996) and Chwe (1999) where such informational problems reverberate through mutual distrust so as to constitute a severe impediment to the efficiency of exchange. To the extent that financial instruments such as bills of exchange are settled using coins of uncertain quality, the standardisation necessary for contractual certainty will also be undermined by the uncertainties in the value of commodity money. The seed of uncertainty can feed and amplify the potentially corrosive effects of incremental erosion of the precious metal content of circulating coinage when two parties to a transaction do not have common knowledge of the values underpinning an exchange.

Currency debasement has occurred on numerous occasions throughout history, but the Kipper- und Wipperzeit raises a number of important questions. The first is why the exchange rate between inferior and superior monies does not adjust to reflect the different intrinsic value of the two currencies. Once the prices adjust in this way, and a fair rate of exchange is established, then both currencies would circulate, but at prices that reflect the fair premium or discount. Rolnick and Weber (1986) cite several historical episodes from the United States and Great Britain, where precisely such an adjustment happened.

Our model of the Kipper- und Wipperzeit stresses several features of the political and institutional landscape of the time that we believe proved to be a fertile environment for the "race to the bottom." We build on two features in particular:

- the political fragmentation of the states within the Holy Roman Empire, and the associated fragmentation of minting activities across the states; and

- the "international" nature of the trade within the Holy Roman Empire, where the trade in goods and money was conducted across jurisdictions.

The first bullet point refers to the fact that, in spite of the attempts to harmonise minting across the Empire, it remained in the realm of the regional princes to mint their own coins.[3] The minting of coins was an important part of the states' revenues through seignorage. The fragmentation of minting was responsible for the large variety of coins that circulated. Through trade, the different coins would spread across regions. Our model builds on the feature that (at least some) traders within a particular jurisdiction would be more familiar with the average quality of coins produced within their own jurisdiction, but would have less familiarity with the average quality of coinage produced in other regions. In this sense, asymmetric information lies at the heart of our story, akin to Akerlof's (1970) "lemons" problem. However, the nature of the asymmetric information differs from the original lemons problem in that the asymmetric information would apply symmetrically to both sides of the transaction. One side has better information about his own coins than the other side; but no one has an absolute advantage over the other. In this sense, the asymmetric information applies "symmetrically."[4]

The establishment of public deposit banks secured standardisation of the units of settlement by replacing the direct exchange of coins (which is beset with problems of adverse selection) with the balance transfers across accounts in the deposit bank. Even if the coins backing the deposits were of uncertain quality, such uncertainty affects all account holders equally and symmetrically. The fundamentals would be uncertain, but the uncertainty is common knowledge. The advantage of payment via the deposit bank would be reinforced if the quality of coins at the deposit banks were of higher quality.

In our model, the standardisation of contracts enables traders to enter the market with less fear of expoitation, reinforcing the pool of potential trading counterparties when entering the market. So, the more traders that enter as potential buyers, the more will potential sellers too be attracted to

[3] A similar problem existed in the United Provinces, although to a lesser extent (van Dillen (1934, p. 81)).

[4] We are not the first to provide an explanation for Gresham's Law based on asymmetric information. As well as Akerlof's (1970) original contribution, Aiyagari (1989), Banerjee and Maskin (1996) and Velde et al. (1999) have presented adverse selection models of Gresham's Law. Our incremental contribution is to show the importance of common knowledge.

enter the market, which in turn reinforces the incentives for other buyers to enter. Thus, the initial "seed" of standardisation of units of settlement sets off a virtuous circle of greater market participation, thicker markets and the greater capacity of the financial system to facilitate the consummation of real economic transactions.

The outline of our paper is as follows. After setting the stage with a brief description of the history of the crisis, we present institutional details on the deposit banks founded in Amsterdam and Hamburg, and compare their performance with other, less successful deposit banks of the era. We then sketch the theoretical arguments on how two-sided asymmetric information about coin values could make the system vulnerable to Gresham's Law and the spread of the debasements across regional borders; the role of the public deposit bank stemming the crisis builds on the theoretical arguments. Our formal model is presented in the appendix.

2 Historical background

2.1 The Augsburg imperial mint ordinance

In 1559, the Holy Roman Empire sought to harmonise its coinage system by issuing the Augsburg imperial mint ordinance ("Reichsmünzordnung").[5] According to this decree, minting was to be carried out by a selected group of princes maintaining a limited number of mints. Mints could not be sold or leased. The export of domestic money or silver was prohibited, and the amount of foreign coins limited. The intrinsic content of coins was to be fixed throughout the denomination structure; even small coins were full-bodied. The alteration of coins was to be punishable by death. The supervision of minting was delegated to the Imperial Circles, which employed coin inspectors ("Kreiswardeine") and organised regular "probation days" where inferior coins were declared void. Mint masters who were responsible for the production of inferior coins were to be punished.

The ordinance put the Empire on a bimetallic standard. The largest coins (*Dukaten*) were gold, whereas all the other coins were silver. Although there were regional variations, the *Reichstaler* underpinned the silver coinage. By decree, 9 Reichstaler were to be minted from 1 Mark silver of Cologne (approximately 234 grams). In southern Germany, the *Gulden* played a comparable role. Smaller-denomination coins were the *Kreuzer* and *Groschen*,

[5] Note that the mint ordinance did not apply to the Netherlands, Switzerland, and some of the Western border regions (Schneider (1981, p. 48)).

although there was great regional variation in the names.[6]

However, the mint ordinance was flawed in its implementation. Given the higher costs of producing subsidiary coins, the minting of small coins proved to be unprofitable. The official mints stopped producing small coins, which led to a shortage of small change. As small coins were needed for daily transactions, some unauthorised mints (so-called "Heck(en)münzen") started to mint inferior coins which allowed for at least some seignorage profit. The strong increase in the number of mints put pressure on the price of silver, which induced the mints to reduce the silver content of coins even further. Later even the official mints started to take part in the coin-making business. Coin supervision proved to be ineffective (Schneider (1981, pp. 48–49)), and the prohibition of coin adulteration was not enforced.

2.2 Creeping debasement of small coins

The increasing circulation of debased subsidiary coins implied a creeping increase in the price of large coins (which were still largely full-bodied) in terms of small coins. Averaged over the Empire, the Reichstaler increased between 1582 and 1609 from 68 to 84 Kreuzer, a devaluation of the Kreuzer of one fifth (Shaw (1895, p. 103)). The process was fuelled by the looming war, which induced the princes to prepare a war chest by increasing seignorage revenues and set the stage for the ensuing hyperinflation. One well-studied case was that of the Duke of Braunschweig–Wolfenbüttel. In 1617, he ordered the coining 210 Groschen from 1 Mark silver compared with 110 according to the ordinance. By 1621, this number went up to 330 Groschen, implying a decrease of the silver content by two thirds. More and more states started to violate the imperial mint ordinance. The bad money also spilled over to regions not issuing adulterated coins, not only within the Empire, but also across its borders, e.g., to the Netherlands.

2.3 Hyperinflation and the "Kipper- und Wipperzeit" (1619-1623)

The Defenestration of Prague in 1618 marked the beginning of the Thirty Years War. The war increased further still the princes' need for revenues, setting the stage for the ensuing hyperinflation. By 1621, the coin standard had been decreased from 9.5 Gulden per Mark silver (as prescribed by the mint ordinance) to 46. The most spectacular deal was concluded in 1622 when a coin consortium led by the banker Hans de Witte from Prague, and

[6] http://pierre-marteau.com/wiki/index.php?title=Money_(Holy_Roman_Empire)

including such famous people as Albrecht von Wallenstein, leased all mints in Bohemia, Moravia and Lower Austria from the Emperor. At the same time, they were granted a monopoly for silver purchases and coin production in those areas. This silver was to be coined at a standard of 79 Gulden per Mark, which was well above the existing standard (46 Gulden). In fact, the consortium diluted the standard even more. Wallenstein and the other members of the consortium benefited from this deal, which allowed him to finance his own army during the war. In addition, the Emperor himself earned an amount of 6 million Gulden from the lease, which was six times his former revenue from Bohemia, including the revenue from minting.

Similar actions were observed in other parts of the Empire, where new mints sprang up "like mushrooms after a warm rain."[7] To provide for a sufficient supply of silver, the mints employed subcontractors who went about buying old coins with higher silver content (paying with debased money at increasing prices) to bring them to the mint to receive larger amounts of debased coins bearing the same nominal values. These people were later called the "Kipper und Wipper".

The initial effect of the enormous monetary expansion was an economic boom. However, eventually, prices started to increase rapidly, and the initial boom turned into hyperinflation and crisis. By this stage, many of the new coins were made almost entirely of copper. Redlich (1972, pp. 11) claims that the Empire was by this time on a *de facto* copper standard. The increasing scarcity of copper even led people to bring their pots and pans to the mints. More and more often, trade and business came to a standstill. Craftsmen and farmers were no longer willing to sell their services and products for worthless money. Tax revenues also ran dry, as taxes were paid in copper money. Rising prices were followed by riots in many big cities including Erfurt, Halberstadt and Kassel, often directed against the money changers rather than the sovereigns (Scheinder 1981, p. 72). As the debasement spiralled out of control and people were no longer willing to accept the worthless money, one mint after another ceased its operations.

2.4 Public deposit banks and stabilisation

The monetary crisis led to the foundation of the major deposit banks of northern Europe. The Bank of Amsterdam pre-dated the crisis, having been founded in 1609. Other deposit banks followed in Middelburg (1616), Hamburg (1619), Delft and Nuremberg (both 1621). The Banks of Amsterdam and Hamburg are the best known, and were to play an important role in

[7] Langer (1978, p. 30) as cited in Kindleberger (1991, p. 160).

subsequent centuries (see Schnabel and Shin (2004)). The Bank of Amsterdam was modelled on the Venetian Banco della Piazza di Rialto (founded in 1587), but the goal was quite different. In Venice, the bankruptcy of the private deposit banks caused by excessive lending had led to the establishment of a public bank; in Amsterdam, the purpose was to quell monetary disorder.[8]

The Bank of Amsterdam functioned as follows. Coins could be deposited, and the respective amount would be credited in a notional currency, called *bank money*. Bank money could be transferred to somebody else's account by assignment, avoiding the costs and pain of transferring the coins directly. Importantly, the quality of coins would be assayed at the time of deposit to ensure that only full-bodied coins would enter the bank. This was to provide for a stable relationship between bank money and "good" commodity money. In contrast, circulating money could be worn, clipped or debased, implying a high degree of uncertainty in transactions involving circulating coins. As a consequence, bank money typically bore a premium (called agio) compared with the circulating money. One reason for this was the quality differences between deposited and circulating coins, but also a reduction in uncertainty, which made the bank money more valuable for the merchants - akin to the liquidity premium we see in modern financial assets.[9]

Deposit banks evolved in the major tradings centres of the time. In trade, monetary uncertainty was particularly harmful because foreigners would be even more sceptical regarding the value of coins. In fact, the foundation of the deposit bank in Amsterdam had been preceded by private initiatives of merchants who deposited full-bodied coins at cashiers and established a cashless payment system among the participating merchants. However, such activities were soon prohibited; the fear was that good coins would be withdrawn from circulation, thereby accelerating the depreciation of the currency (Soetbeer 1866, p. 24)). At first, the idea of a bank was looked upon with the same suspicion by the general public, and it was only at the merchants' insistence that the bank came into existence.

Originally, the Bank of Amsterdam was no fractional reserve bank; the creation of bank money was, at least de jure, strictly limited by the amount of gold and silver in the bank's vaults. The credibility of this arrangement relied substantially on the ability of the bank to commit to not diluting the value of the bank money. The bank benefited from a government guarantee, and it was controlled by the merchants themselves, who had a collective

[8] See van Dillen (1934, pp. 80, 85), Kohn (1999) and Fratianni and Spinelli (2006).

[9] According to Adam Smith (1776 [1991], pp. 421, 426), the typical agio was around 5 percent in Amsterdam and 14 percent in Hamburg.

interest in monetary stability.

The credibility was eroded somewhat by the creation of a lending bank in 1614, which was established primarily to extend loans to the public authorities, but also to extend lombard loans against collateral, mostly coins and bullion.

Note that the bank also allowed for the creation of money through the writing of bills of exchange, which were crucial in international payment transactions. Any account holder could write bills in terms of bank money. In fact, the bank law prescribed that bills of exchange above a certain amount had to be settled in bank money. This possibility of money creation provided an additional threat to the stability of bank money. There was no mechanism to prevent account holders from writing huge amounts of bills on the basis of their bank accounts.

However, in spite of these limitations, Amsterdam bank money soon emerged as the key currency in international finance.The legendary reputation of Amsterdam bank money was fostered by the large stocks of precious metals in Amsterdam, which arose from the city's dominating position in the bullion trade (Baasch (1927, pp. 2150). The stability of the bank money was rarely questioned.

Similar institutions developed elsewhere, most notably in Hamburg whose financial institutions were almost one-to-one copies of the ones in Amsterdam (Soetbeer (1866, p. 23)). As in Amsterdam, the giro bank was complemented by a lending bank, and the city became the largest debtor from the very beginning; in contrast, loans to private agents were initially negligible (Sieveking (1934, p. 129)). However, the bank's lending activities may not even have been known to the merchants or the general public as the bank's books were kept secret. The bank's success can be inferred from its rapid growth: Between 1621 and 1655, the bank's total assets increased from 832 thousand Marks to 3,506 thousand Marks (Sieveking (1934, pp. 129, 131)).

The Banco Publico of Nuremberg was the only public deposit bank that was founded in the southern part of the Empire. Its foundation was again motivated by the monetary disturbances, and once more it was the merchants who pleaded that it be established. Most of its provisions were adopted from the Bank of Hamburg, with one major exception. Deposits could be made not only in full-bodied, large coins, but also in current small money, both domestic and foreign (Poschinger (1875, p. 21)). Although this arrangement was later discontinued, it undermined the bank's credibility from the outset. It implied that the uncertainty of the value of bank money was not removed because part of the bank's coins was possibly less valuable than determined in the mint decree.

In addition, the bank extended loans to the public authorities from the

very beginning, even though this was prohibited by the bank's statutes. In 1623, such loans amounted to almost one third of the bank's total assets (Poschinger (1875, p. 36)). The abuse worsened in later years when the bank's vault was virtually plundered by the city's officials such that the bank was sometimes not even able to repay deposits on demand (North (1994, p. 117), Poschinger (1875, p. 29)). Against this background, the bank's total assets decreased sharply in the early years after its foundation. Other than in Amsterdam and Hamburg, the volume of the bank's deposits remained too small to establish a widely used bank money for trade transactions.

Early writers like Adam Smith appear to have admired institutions such as the Bank of Amsterdam. Kindleberger (1991) also describes the banks as having been a success. In contrast, van Dillen (1934) provides a more nuanced assessment regarding the ability of the banks to mitigate the monetary disturbances: "The irony of history... would have it that ... the world-famous institution [the Bank of Amsterdam] was not to succeed [in improving monetary conditions]." Van Dillen's judgment appears to be based on the observation that the devaluation of the currency was not stopped completely. On the other hand, given that bank money was used only in wholesale transactions, this may not come as a surprise. Also, it should be noted that the debasement in Amsterdam and Hamburg was much smaller than in other places that did not have a public deposit bank.

Other than the Banks of Amsterdam and Hamburg, the Banco Publico of Nuremberg clearly seems to have failed in its goal of establishing monetary stability. Arguably, this stemmed from the serious flaws in the bank's organisation: First, the deposit of coins had not been limited to full-bodied coins; and second, the bank was not able to escape the grasp of the public authorities on its vault, which diminished its credibility. The same problem loomed at the other banks when the giro banks were supplemented by lending banks. Thereby, the banks de facto became fractional reserve banks and became vulnerable to bank runs; in fact, such runs recurred in the later history of the banks, and were countered by the banks' temporary closure (similarly to the "suspension of convertibility" discussed in the bank run literature; see Diamond and Dybvig (1983)). Also, similarly to the Bank of Nuremberg, the Bank of Hamburg was repeatedly abused as financier of the state – though not to the same extent.

2.5 Issues to be addressed

The applicability of the simple version of Gresham's Law – that bad money drives out good – needs to be qualified. One important question is why different types of coins would not circulate at an exchange rate reflecting

their intrinsinc values (what is called "circulation by weight"). One strand of the literature argues that the exchange rate between the two monies is fixed (so-called "circulation by tale"), for example, due to legal tender laws, mint exchange policies, or conventions (see, e.g., Sargent and Wallace (1983), Sargent and Smith (1997), and Li (2002)). However, Rolnick and Weber (1986) argue that such a stance is untenable, from both an institutional and an empirical point of view. Indeed, Rolnick and Weber cite several comparatively recent historical episodes from the United States and Great Britain where different types of coins circulated side by side at a floating exchange rate. For instance, during the early 19th century in the United States, both the U.S. silver dollar (containing 371.25 grains of silver) and the Spanish milled dollar (with 373.5 grains) circulated concurrently, with the Spanish dollar circulating at a premium over the U.S. dollar, the premium ranging from 0.25 percent to 1 percent. But the occasional circulation of coins according to their intrinsic values does not exclude the possibility that there were deviations from the circulation by weight at other times. In fact, we will see that such deviations are important to understanding the observed spread of debasements across regions.

The other strand of the literature on Gresham's Law is based on the assumption of asymmetric information about coin values, generating a problem akin to Akerlof's lemons problem (see, e.g., Aiyagari (1989), Banerjee and Maskin (1996) and Velde et al (1999)). Commodity money has always been plagued by problems of asymmetric information because the intrinsic value of coins, and especially their fineness, could be checked only at relatively high costs. The technologies used to assay the fineness of coins have been described in some detail by Gandal and Sussman (1997, pp. 443–444): The most common, but relatively crude technology was the "touchstone test," in which the trace from rubbing a coin on a special stone was compared with that left by a metal of a known fineness. A higher precision could be obtained only by assaying by fire (essentially the melting-down of the coin), which was much more costly and implied a loss of the coin itself.

The monetary system worked on the principle that individuals could bring metal to the mint (controlled or authorised by the sovereign) to be made into new coins; this is often referred to as "free minting" or "free coinage" (see, e.g., Redish (1990) and Sargent and Velde (2003)). In such a system, the quantity of coins minted is determined by the public's decision to bring silver or gold to the mint. The sovereign determines the prices at which minting takes place by setting the mint equivalent and the seignorage rate (see Redish (1990), Sussman (1993) and Sargent and Velde (2003)): The *mint equivalent* (or mint par) was the value of a given weight of precious metal in terms of the numeraire currency; it depended on the number of coins struck from the

metal, on their fineness and on their nominal value. A certain fraction of the minted coins – the (gross) *seignorage rate* – was kept by the mint to cover minting costs (brassage) and the seignorage tax. The seignorage tax went to the sovereign and constituted an important source of fiscal revenue, especially in times of war. Hence, the price at which precious metal could be sold at the mint – the *mint price* – was below the mint equivalent, implying that the minting of new coins was a costly activity for the individual who brought in the metal.

The sovereign could debase his coinage in three different ways (see Sussman (1993)): First, by increasing the number of coins struck from the alloy, which would alter the coins' weight and could, therefore, be detected with a scale; second, by increasing the coins' nominal value, which was even more transparent; and finally, by changing the coins' fineness, the detection of which required rather sophisticated technologies, as described above.

In addition, coins could be clipped by the general public, which would again change the coins' weight and could, therefore, be detected by using a scale. In the model, we will focus on debasements where the sovereign changes the coins' fineness, even though other kinds of debasements were observed in the considered time period.

The new (debased) coins could enter circulation not only when fresh bullion was minted, but also when old coins were re-minted. Rolnick et al (1996) point out some telling empirical regularities associated with debasements. Seignorage rates tended to be high during episodes of currency debasement, leading to substantial revenue for the sovereign. However, these periods also saw very large volumes of (re-)minting activity. Rolnick et al. (1996) report that, between 1285 and 1490, France had 123 debasements of silver coins, 112 of more than 5%. In normal years, government revenue due to seignorage constituted less than 5% of the total; but in debasement years, it could be as high as 50% due to increases in both the seignorage rates and mint activity. As discussed above, the same applied to the Kipper- und Wipperzeit. Seignorage was substantial, and so was the re-minting activity.

The question is why there was an incentive to engage in the re-minting of coins in spite of the subtracted seignorage. If coins had circulated according to their intrinsic values, there would not have been an incentive for re-minting older coins due to seignorage. Again, one needs some deviation from the circulation by weight to explain re-minting activities. If, at the other extreme, coins circulated by tale, re-minting would always be profitable if the new mint price exceeded the old mint equivalent (Sussman (1993)).

Summing up, a satisfactory theoretical account of the events surrounding the Kipper- und Wipperzeit should address how the debasements could spread across regional borders and why there was so much re-minting in

spite of the substantial seignorage tax. Based on our historical account, the following important features figure in one version of our model: the fragmentation of minting across states, the existence of a seignorage tax, the two-sided asymmetric information as described above, and the prevalence of trade in goods and money across jurisdictions.

3 Elements of a theory

The Kipper- und Wipperzeit stands out from other episodes of currency debasement in that the debasement was not limited to a single state, but spread from one state to another. Kindleberger (1991, p. 149) writes that "the process spread through Gresham's Law: bad money was taken by debasing states to their neighbors and exchanged for good. The neighbor typically defended itself by debasing its own coin."

One version of our formal model builds on the following features:

- the double-sided asymmetric information concerning the quality of coins, and the attendant adverse selection problems;
- the interaction of the "seed" of adverse selection and the mutually reinforcing nature of market participation;
- the fragmented and decentralised nature of minting activity and the incentives facing an individual state when faced with debasement in surrounding states; and
- the importance of common knowledge in transactions, and how deposit banks restored the standardisation necessary to underpin efficient exchange.

We take each of these features in turn, and explain how the pieces fit together in the overall explanation of the Kipper- und Wipperzeit.

3.1 Adverse selection

In order to set the framework of our argument, consider a simplified setting with two jurisdictions, overseen by a central authority. Both jurisdictions use silver money, and are on the same official coin standard. However, the central authority is too weak to enforce the standard and cannot prevent the debasement of coins by the regional sovereigns. The decentralised nature of the official interventions is important for our argument. Denote the quality of coins in the two jurisdictions by v_1 and v_2, respectively, where we may think

of v_i as the relative silver content of the coins in jurisdiction i relative to the full-bodied ones. When the quality of coins is not uniform, v_i should be considered a random variable, with an associated distribution over qualities in i.

The merchants in country i can affect the overall density of v_i by withdrawing existing coins from circulation and re-minting them. The regional sovereign can affect the density of v_i by determining the minting standards in i. The quality of coins cannot be easily determined without their undergoing costly examination, such as assaying by fire. Hence, most traders cannot make fine distinctions between coins of similar quality. However, it would be reasonable to assume that merchants in one jurisdiction have better information concerning the quality of the coins circulating in their own region, compared with coins circulating in the other region. For our argument to be valid, it suffices to make the moderate assumption that proportion π of the merchants in region 1 know what the true average quality of the coins in circulation in their own region is, but are uncertain about the average quality of coins predominating in the neighbouring region. The rest (proportion $1-\pi$) do not even have this modest information.

Consider a mechant from country 1 who would like to buy goods from country 2. He would pay for the goods by shipping coins from country 1 to the sellers in country 2. Alternatively, the merchant from 1 can issue a bill of exchange that is redeemable in the coins of 1 at the maturity date. Either way, the merchant from 1 who knows the true average quality of coins in 1 has an advantage in the transaction. Relative to trade in terms of full-bodied coins, the informed buyer from country 1 knows the (expected) gain by paying for the goods in terms of debased coins. The situation is exactly symmetrical from the point of view of merchants from country 2. Let us apply the same assumptions for country 2. Proportion π of merchants in 2 know the true average quality of coins circulating in 2, and the rest $(1-\pi)$ do not.

The sellers of goods in countries 1 and 2 face a dilemma. The goods they are giving up to buyers from the other region are of known consumption value (for the sake of argument, we may assume identical, risk-neutral preferences). However, they receive in return coins of *uncertain value*. More importantly, they realise that the buyers who are most keen to purchase the goods are those who know that the coins they are using to purchase the goods are of low quality. In this sense, the keener the buyer to buy a good, the more wary should the seller be. In the extreme case where the adverse selection is severe, the sellers would be better off refusing to trade with any buyer, since only the buyers who offer debased coins will offer to trade with them. This is the well-known "Groucho Marx" problem in trade with asymmetric information,

with reference to the Marx Brothers' film where Groucho famously announces that "I refuse to join any club that would have me as a member."

The adverse selection problem described above is a variation on the lemons problem described by Akerlof (1970), except that the asymmetric information afflicts both sides along two dimensions. By this, we mean that country 1's merchants have an advantage in buying goods from country 2, while they are at a disadvantage when they are sellers of goods to buyers from country 2. Thus, neither group has an absolute advantage over the other group. Instead, they each have a relative advantage along one dimension.

3.2 Amplification through market participation

The adverse selection effect is the "seed". The large economic damage comes through the amplification effect of withdrawal from market participation. One of the important functions of markets is to match buyers with sellers, so that they can consummate trade on mutually beneficial terms and thereby realise the potential economic surplus. In doing so, the market mechanism relies on the mutually reinforcing effect of market participation.

Take a simple hypothetical example. When a seller contemplates whether to take his produce to the market, he weighs up the pros and cons. By taking his produce to the market, he will lose a day's work, and therefore incur cost. Thus, he will only choose to take his produce to the market if he believes that there are sufficient potential buyers at the market to make it worthwhile. The more potential buyers there are, the more worthwhile it is to incur the cost and participate as a seller.

The situation is exactly symmetric from the point of view of the buyer. The buyer will go to the market only when there is sufficient likelihood of sellers turning up with goods for sale. Thus, from the point of view of the buyer, the incentive to participate is greater when the expected seller participation is greater. The mutually reinforcing effect of seller/buyer participation has been much discussed in the literature on thick market externalities (Diamond (1982), Pagano (1989) and Shin (1996), among others), and the design of trading platforms in financial exchanges and the rules governing them have been shown to depend sensitively on the strength of such externalities. When markets work well, the externalities operate in a virtuous way. Because buyers believe that sellers will participate actively, they are happy to submit aggressive (i.e. large) bids without worrying that such action will simply result in the price being bid up in a thin market. The sellers, for their part, anticipate such behaviour, and are happy to submit large quantities without fearing that this will simply drive down the price in a thin market. The virtuous circle of beliefs results in the desirable outcome

where transactions are large and there are large gains from trade.

However, a seed of doubt is planted by adverse selection, the externalities that led to the virtuous circle can work in reverse, and the market may spiral down to a very different outcome. When the seller fears that his goods will be paid for with debased coins, he will be wary of how much the buyer knows about the quality of the coins he is carrying (or will be released at the time of redemption of the bill of exchange). In particular, the greater the probability that the buyer is bringing debased coins, the more reluctant the seller is to part with his goods. This is the Groucho Marx phenomenon alluded to above.

However, if this is the reaction that a potential purchaser is likely to face, then the buyer will think twice before setting off to market. Even those buyers who do not have privileged information will be cold-shouldered by the sellers. Thus, the uninformed buyers are the first group to be discouraged from going to market. The result is that the pool of potential buyers is weighted heavily in favour of those buyers who know that the currency they are carrying is debased. The sellers can anticipate all this, and so are fully justified in their wariness when facing a buyer. Trade therefore is much less likely to take place, and so sellers are much less likely to take the trouble to come to market in the first place.

This is a classic example of an inefficient equilibrium. The actions of each individual are rational given the circumstances that he faces, but the resulting aggregate outcome is undesirable from a welfare point of view. There are large potential gains from trade that are left unexploited. The main losers are those uninformed traders who would ideally have traded with each other, but are unable to do so in equilibrium due to the unravelling effect imparted by the "seed" of adverse selection.

3.3 Incentives of the sovereign

A key feature of the propagation of the currency debasement is the fragmented and decentralised nature of the minting activity. We go back to our simplifed two-country setting with countries 1 and 2. We noted above Kindleberger's (1991, p. 149) argument that "bad money was taken by debasing states to their neighbors and exchanged for good. The neighbor typically defended itself by debasing its own coin." It is important to understand why debasing one's own coins could be seen as "defending" the country from the onslaught from the neighbouring country.

First, it is worth asking what motivates the sovereign. It would be reasonable to suppose that the sovereign has a fiscal incentive towards debasement arising from the revenues raised through seigniorage. Indeed, such a motive

lies at the heart of episodes of "controlled" debasement where the sovereign deliberately engineers the debasement of a fixed size so as to raise revenue.

However, even if the sovereign did not have such motives, there are good reasons to "defend" the currency through a matching debasement when faced with a flood of debased coins from neighbouring regions. The motive is closely related to the competitive devaluations that occur in modern times. Suppose, for the sake of argument, that the sovereign in country 1 does not have a fiscal motive to debase the currency in 1. However, when debased currency from 2 is exchanged for the full-bodied coins from 1, the full-bodied coins will be withdrawn from circulation or exported to be melted down. The result would be a lowering of the money supply in 1, and the associated economic effects of tight money. A matching debasement by 1 remedies the situation by removing the margin of profit for those who seek to exchange bad money for good.

Of course, if the sovereign also had a motive to raise revenue, then the argument for a matching deviation would be even stronger. In this sense, the sovereign would need very little encouragement to follow the path of matching debasement. Indeed, there would be a strong argument for selecting a level of debasement that slightly exceeds the debasement in the neighbouring region, since this would be the prudent strategy in a world where the exact quality of coins is uncertain, and the onus is on pre-emptive action in a world of fast-moving events.

The "race to the bottom" comes when the competitive debasements reach such a pace that one country races to keep up with the debasement from the other country as the best response, and in turn the other country's rapid debasement is its own best response. In a decentralised setting where the actions of the sovereigns do not come under strong central control, the individually prudent actions of individual sovereigns would lead to the collectively disastrous outcome of a race to the bottom. As with traders, the sovereigns themselves face a collective action problem, and the spread of debasement is the outcome of that problem. The fragmented nature of the Holy Roman Empire during the Kipper- und Wipperzeit is therefore an important ingredient of our scenario of events.

3.4 Deposit banks

We have argued how trade and the associated information problems can give rise to a variant of Gresham's Law where good coins are re-minted or withdrawn, even though, in equilibrium, this reduces the traders' profits and social welfare. Crucial to our argument has been the combination of (i) the fragmented nature of the institutions that allow the incremental debasements

to take place, and (ii) the two-sided asymmetric information that follows from cross-border trade. We will now discuss how the public deposit banks may have served to remedy these problems.

Let us consider the following features of an "ideal" public deposit bank, abstracting from the weaknesses observed in practice:

1. Coins could be deposited at the bank only after the quality of the coins had been verified.

2. The banks created a notional currency ("bank money") to be used for payments.

3. All bills beyond a certain amount had to be paid at the bank.

4. Banks were publicly guaranteed.

We want to argue that the combination of these features generated *common knowledge* of the value of money, and thereby prevented the socially inefficient erosion of coin values. We propose two reasons for how the deposit banks managed to arrest the erosion of coin values:

- better guarantee of the value of the claims underpinning monetary transactions; and

- standardisation of the terms of settlement.

The two reasons, although related, can be taken separately. Indeed, of the two, the second factor is of potentially greater importance for the subsequent development of the financial system.

The first feature (control of the quality of the coins deposited) ensured that any depositor would be credited the "fair" value of the deposited coins. The control could take different forms. One was the restriction of the types of coins that were accepted for deposit. Indeed, the Banks of Hamburg and Amsterdam applied such restrictions. For example, coins that were known to have been subject to serious debasements were not accepted. In the framework of our model, it would suffice to allow only for the deposit of domestic coins, the quality of which could easily be checked by domestic traders (and, hence, by the bank). In contrast, the lack of such restrictions at the Bank of Nuremberg may explain its limited success. The quality of coins could also be checked by using the assaying technologies described above. It is likely that the relatively cheap tests, such as the use of a scale or the "touchstone test", would always have been carried out for that purpose.

However, since the quality of coins would have to be verified only once, even the "assaying by fire" may have been worthwhile, given that it would have to be carried out only at the time of deposit. Hence, the costs would be negligible, relative to the total circulation of money. Ideally, the controls would ensure that the value of coins in the bank's vault – and hence the value of the notional currency – would correspond to that prescribed in the mint ordinance.

Payments would be executed through cashless transfers or, alternatively, through bills of exchange, denominated in the notional currency. Bills of exchange were particularly important in international transactions between parties that did not both have an account at the same deposit bank (see Schnabel and Shin (2004) for the use of bills of exchange in international trade). In fact, in Amsterdam and Hamburg only merchants from the bank's jurisdictions were allowed to open an account at the bank. The provision that all bills of exchange above a certain amount had to be paid at the bank implicitly forced all merchants to open a bank account. It provided for a centralisation of coins at the deposit bank, thereby ensuring that the network of merchants making use of the bank money was large enough; this raised the bank money's attractiveness due to the existing network externalities in the use of money. Moreover, the willingness of the domestic traders to forgo the option to write bills outside the bank was a signal to foreign traders that the payment mechanism was reliable.

The guarantee of the city lent some additional credibility to these arrangement. In fact, it is quite striking that the banks were founded in free cities, rather than principalities. In a free city, the interests of the government and the merchants would be much more aligned than in a principality, where the hunger for seignorage taxes may have outweighed the interest in maximising social welfare. While the banks were established primarily for the benefit of the Amsterdam or Hamburg traders, their establishment also benefited their trading partners. Just as the debasements tended to spread along trade itineraries, the stabilisation would spread along the same routes. Hence, the creation of public deposit banks had the character of a public good. At the same time, this may help explain why so few deposit banks were created in the Empire. First, the regional benefit had to be great enough to make the costs of establishment worthwhile; this would be true most of all in the major trading cities like Hamburg and Amsterdam. Second, given the establishment of banks in other places, the other regions could free-ride on the stability provided by these banks. However, these other places may have underestimated the impact that the creation of the banks would have on the future economic development of the respective regions.

We now turn to the second factor - the standardisation of settlement.

By replacing the direct exchange of coins with the balance transfers across accounts at the deposit bank, the settlement through bank money established the critical feature of the level playing field in information. To explain this point more fully, it is worth emphasising that the standardisation argument is logically independent from the argument on the quality of coins backing the claims at the deposit bank. Even if the coins backing the deposits were of uncertain quality, such uncertainty affected *all account holders equally and symmetrically.*

The agio between bank money and circulating currency can be understood in those terms. As discussed by Quinn and Roberds (2007, 2014) and by authors as long ago as Adam Smith, bank money almost invariably traded at a premium to the circulating currency. The premium fluctuated around a large margin, ranging from less than 2 percent to over 5 percent. Part of the reason for the agio can no doubt be attributed to the higher absolute quality of the coins held at the bank to back the deposit claims. However, even if there were no difference in coin quality, there would still be a good reason for the existence of the agio.

The most important economic impact of standardisation is the fostering of orderly market transactions that allow economic gains to be realised through trade. The standardisation of contracts enables traders to enter the market with less fear of expoitation, reinforcing the pool of potential trading counterparties that others will look to when entering the market. As emphasised above, orderly markets allow the virtuous circle of thick market externalities in which more traders enter as potential buyers believing that more potential sellers will be attracted to enter the market too. Once these beliefs have taken hold, self-interested actions reinforce the virtuous circle.

The preconditions of standardisation and common knowledge of units of settlement lie at the heart of the virtuous circle of greater market participation, thicker markets and the greater ability of the financial system to facilitate the consummation of real economic transactions. These factors are reminiscent of the arguments put forward for the establishment of common accounting standards and the standardisation of documentation of derivative contracts that have driven the development of financial market institutions in recent decades. To the extent that the public deposit banks were the precursors of standard-setters, there can be little doubt that the Bank of Amsterdam and its imitators such as the Bank of Hamburg kick-started the financial deepening and financial innovation that propelled the two cities to the forefront of global finance in the subsequent decades.

3.5 Common knowledge and money

Common knowledge refers not only to the fact that everyone knows, but that this knowledge is transparent to all concerned. Another way to state this feature is that everyone knows, everyone knows that everyone knows, and so on without limit. The idea is not that individuals hold these infinite hierarchies of knowledge in their minds, but rather that they face a very transparent situation where no doubts exist about such higher orders of knowledge.

The philosopher David Lewis provided a celebrated analysis of why common knowledge is key to social conventions (Lewis (1969)), and common knowledge is also the cornerstone of the analysis of equilibrium in economics.

The importance of common knowledge is especially relevant in monetary economics in the age of DLT, as one interpretation of money is as a score-keeping device on past transactions. The maxim is "money is memory". Indeed, Kocherlakota's (1998) paper has precisely this title, and in the setting of his analysis, a costless, publicly accessible record of all past transactions can achieve the allocation of goods through transfers as would be feasible in a monetary economy.

The following concrete example illustrates the argument. Suppose that three individuals, A, B and C, each hold a good that is more valuable to one of the other two individuals, but there is no double-coincidence of wants whereby a direct swap between two individuals makes both better off. Money enables the three individuals to trade, and enables them to achieve the efficient allocation of goods. Generalising such an argument, Kocherlakota (1998) notes that if a ledger that records all past transactions is common knowledge, then an impartial referee can keep track of the transfer of goods, and implement the same allocation of goods to individuals, as is possible in a monetary economy. The costless ledger of all transactions would open the possibility of mimicking the allocation of a monetary economy through a sequence of recorded gifts from one person to another.

This brings us to the topical issue of how Bitcoin and other uses of DLT technology can be used to implement such a ledger of past transactions without the need for a centralised impartial referee. Kocherlakota's (1998) maxim that "money is memory" raises the intriguing question of whether DLT can substitute for the role of money in providing decentralised social memory.

There are, however, two considerations that give pause for thought. The first concern is the robustness of the argument that memory can substitute for money. The ledger that keeps score of past transfers must be commonly shared. Bhaskar (1998) and Bhaskar et al (2012) show that small departures from the common knowledge of infinite histories of transactions will undermine the incentives in such settings, rendering the monetary outcome

infeasible. This is so even if the record-keeping device is costless.

Bhaskar (1998) cites the example of Samuelson's (1958) overlapping generations model. At each date, the young generation have two units of a perishable consumption good, and the old generation have none. In one allocation, the young consume both goods, but starve when old. However, a better outcome is if the young generation transfer one unit of the consumption good to the old, in the expectation that they will receive from the next generation a similar transfer. Such an allocation is feasible under common knowledge of histories of infinite length - for instance, through "punishment" strategies where a new young generation withhold the transfer of the good if they find that the current old generation that consumes both units. However, when information is limited to finite histories, the good outcome may no longer be feasible through such a strategy as the current old generation had consumed both units may be doing so purely as part of their own punishment of their predecessors (see Bhaskar (1998)). This is yet another instance of the observation that higher orders of knowledge of increasing depth do not approximate the outcome with common knowledge (see Morris and Shin (1998, 2003) for more details). Bhaskar et al (2012) show that departures from common knowledge severely restrict the scope of score-keeping devices to implement cooperative outcomes so that only equilibrium in Markov (that is, history-independent) strategies can be supported as robust equilibria.

There is a second concern with the "money is memory" maxim. The argument for this maxim rests on showing that the efficient allocation is only one possible outcome as an equilibrium. Other, much less desirable outcomes could also emerge as equilibria. Which outcome emerges will depend on the robustness of the equilibrium selected.

Although these theoretical debates may seem abstract, they go to the heart of the current debates about the role of DLT. The theoretical arguments on money as memory depend sensitively on the common knowledge of the histories and the unbounded nature of the recorded transactions.

The importance of common knowledge in economics applies to a wide range of situations. It is worth taking a step back to highlight the abstract properties of common knowledge so as to better understand the economic impact of the absence thereof. Consider the following thought experiment. A large, disparate group of individuals face a collective action problem. Suppose that the preconditions for a successful coordination are in place, and it is just a matter of conveying the facts of the case to the individuals. Compare three scenarios for conveying this information taken from Morris and Shin (2007).

- Send an email to each individual, stating that the preconditions for a

successful coordination are in place. But each individual recipient does not know who else has been sent the message.

- Send an email to each individual with the same content as above, *but with the recipient list clearly visible.*

- Rather than relying on email, convene a meeting of all the individuals concerned. Gather everyone in a conference room, where each individual can clearly see everyone else in the room. Then, make an announcemement to the gathered group that the pre-conditions for a successful coordination are in place.

Although the content of the message or announcement is identical in the three scenarios, they are qualitatively very different situations in terms of generating common knowledge of the circumstances. In the first scenario, even if each recipient of the email trusts the sender as to its contents, this may not be enough to tip the balance towards achieving coordination. The problem is the uncertainty concerning what *other* parties will do. Even if the underlying fundamentals of the problem were known, the uncertainty about the others' beliefs and actions is still all-pervasive. Douglas Hofstadter (1985, pp.752-3) coined the term "reverberant doubt" to describe this type of uncertainty. The idea is that even a small seed of doubt that the players can close ranks to achieve the good outcome will start to undermine the resolve to stick to the cooperative strategy. The small seed of doubt "reverberates" to become a much larger doubt, and when the players catch themselves thinking this way, it becomes a compelling reason to act unilaterally, and opt out.

The second scenario (of sending an email with the recipient list clearly visible) may fare much better in generating common knowledge of the underlying fundamentals, but there may still be issues with whether the receipients have actually read the message. The third scenario (of a public announcement to a gathered group) could be considered the most effective means to generate the common knowledge necessary to achieve the coordinated action.

The email example is intended to emphasise the important distinction between the *quantity* of information and the *shared nature* of that information. Bank money serves the purpose of the shared nature of the information by ensuring the standardisation of settlement. Chwe (1999) has noted that the expected utility from trade may be maximised by making the value of money common knowledge. As an example, he mentions the introduction of "reeded edges", which prevented the "clipping" of coins and made their value publicly verifiable. However, the technological prerequisites for the production of such coins were quite high and became common only towards the end of the 17th century, i.e., well after the foundation of the deposit banks (Sargent

and Velde (2002, p. 270)).[10] The foundation of deposit banks at the beginning of the 17th century may have been another way of making the value of money common knowledge. By pooling good coins and creating a notional currency, these banks created common knowledge among traders about the value of coins. One interesting question concerns the role of the government in this process. In the model devised by Gorton and Penacchi (1990), banks mitigate inefficiencies by making asset values informationally insensitive; however, under certain conditions, the government has to intervene to ensure efficient trading. The public guarantee of the early deposit banks may have played a similar role. Dang et al (2015) develop these arguments to show that debt is the most informationally insensitive security.

4 Conclusion

Our paper has explained how the creation of public deposit banks may have mitigated the monetary disturbances at the beginning of the 17th century. For this purpose, we presented a simple model of debasements in a country with a uniform coin standard but fragmented minting activities. We have argued that asymmetric information about coin values between trading partners promoted the working of Gresham's Law within regions. However, asymmetric information alone is not able to explain why the debasements spread across regions. In the framework of our model, the progagation of debasements can only be explained if exchange rates between regional currencies do not fully adjust to relative average coin qualities. It is an open question for future research whether the assumption of imperfectly flexible exchange rates can also been confirmed empirically.

Against the background of the theoretical model, we then described how the institutional arrangements of public deposit banks were able to remove the existing informational asymmetries and to generate common knowledge about the value of the money used in exchanges. The mechanism worked as follows: The banks created a notional currency, which was backed by the holding of coins, whose quality had been verified at the time of deposit. Since the traders as a group benefited from not debasing their coinage, the bank could credibly commit to not debasing the stored coins. Public guarantees lent some additional credibility to these arrangements. The institutions proved to be so successful that Amsterdam bank money (and – to a more

[10] The common technology used for coin production at the time in Germany was the cylinder press ("Walzenprägewerk"). The screw press ("Spindelpresse"), with which milled edges could easily be produced, had already been invented, but was not in use at the time due to the opposition of the mint masters (von Schrötter (1930)).

limited extent – also Hamburg bank money) became the key currency in international finance for almost two centuries.

The role we ascribe to the public deposit banks is akin to the functions typically conducted by central banks. Therefore, our analysis suggests that the early deposit banks should be thought of as early precursors of modern central banks, contrary to the conventional view that such banks were created much later, mainly with the intention to finance wars. At places where the banks were used to this end, such as Nuremberg, they were never able to establish bank money as a key currency for trade transactions. The significance that the foundation of public deposit banks had may be anticipated by looking at the rise of Amsterdam and Hamburg to the status of key trade and financial centres. This points to a much greater importance of the banks than their immediate impact on the monetary situation of the time, and highlights the significance of financial institutions for economic growth.

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5 Appendix: model

We illustrate the impact of the erosion of common knowledge through a simple example, drawing on Shin (1996). The following model assumes only differential information on the state of the economy and fixed costs to trading.

There are two goods, x and y, and two regions, A and B. In each region, there are n traders who each have an endowment of one unit of x. In region A, the preferences of traders are identical, and given by

$$u_A = x + y \tag{1}$$

Hence, the traders in A consider x and y as perfect substitutes. In region B, the preferences are given by $u_B = x$. Hence, the traders in B do not care about consumption of y. However, traders in B can produce good y using good x as input. The cost (in units of x) of producing y is

$$x = y^\beta/\beta, \qquad \beta > 1. \tag{2}$$

However, there is a fixed cost of production, $F > 0$ (measured in units of good x). Given the preferences and production technology, there is the possibility of mutually beneficial trade as long as the marginal cost of producing y is below the marginal rate of substitution of x against y for region A (which is 1), provided that F is not too large. The first-best solution is when the marginal cost of production is just equal to 1, which occurs when

$$y^{\beta-1} = 1 \Leftrightarrow y = 1 \tag{3}$$

implying cost of $1/\beta$ plus fixed costs F. Provided that the fixed cost is not too large (i.e., $F < 1 - \frac{1}{\beta}$), the efficient outcome is for traders in region B to produce, and to trade with those in region A.

The precious metal content of coins from region A is uncertain. Denote by v the precious metal content relative to full-bodied coins, where v is a random variable whose realisations are at most 1. There are n possible realisations of v, and denote by v_i the ith lowest realisation of v. Hence

$$0 < v_1 < v_2 < \cdots < v_n \leq 1 \tag{4}$$

The traders in region A know the realisation of v, but the producers in region B do not. They have to rely on their signals (described below) to infer v.

We distinguish the real and the nominal price of good y. The real price of good y in units of good x is

$$p = v \cdot \frac{\sum_i d_i}{\sum_i s_i} \tag{5}$$

where d_i is the amount of money brought to market by buyer i, and s_i is the amount of the produced good brought to market by seller i. The nominal price is

$$\frac{p}{v} = \frac{\sum_i d_i}{\sum_i s_i} \tag{6}$$

The fixed cost F is a random variable, and producers in B observe the realisation of F but the buyers in A do not, and must infer it from their own signals. Let

$$0 < F_1 < F_2 < \cdots < F_m \tag{7}$$

be the possible realisations of F, and suppose that $F_m > 1 - \frac{1}{\beta}$. Thus, for some realisations, the producers are better off not producing at all.

With common knowledge, we obtain the following first-order conditions for state (i, j) in a symmetric equilibrium:

$$d(i) = \frac{1}{v_i} s(j) \tag{8}$$

$$s(j)^{\beta} = v_i d(i), \tag{9}$$

where the seller's first-order condition applies only if fixed costs are not too large. Hence, $s(j) = 1$ and $d(i) = \frac{1}{v_i}$ for all states where fixed costs are not too high; otherwise, there will be no production. The real price will be equal to 1, the nominal price to $\frac{1}{v_i}$. Hence, the efficient solution is implemented.

Traders from region A have identical information sets given by $\{v\}$. The traders from region B have identical information sets given by $\{F\}$. But v and F have a joint density $g(v, F)$. Traders from one region will form beliefs about traders in the other region from this joint density.

Denote by $d(i)$ the amount of money taken to market by a typical trader from region A when $v = v_i$, and denote by $s(i)$ the amount of good y produced by a typical seller from region B when $F = F_i$. Let the numbers of traders be large in both regions, so that price effects of imperfect competition can be neglected.

The first-order condition for buyers of y (i.e., traders from region A) is given by

$$\begin{bmatrix} d(1) \\ d(2) \\ \vdots \\ d(n) \end{bmatrix} = \begin{bmatrix} 1/v_1 & & 0 \\ & \ddots & \\ 0 & & 1/v_n \end{bmatrix} \begin{bmatrix} & Q & \\ & (n \times m) & \end{bmatrix} \begin{bmatrix} s(1) \\ s(2) \\ \vdots \\ s(m) \end{bmatrix} \tag{10}$$

where the matrix Q is the matrix of conditional densities derived from the joint density over v and F. The optimal decision now depends on the *expected* supply instead of the realised supply.

The first-order condition for sellers is

$$\begin{bmatrix} \hat{s}(1)^{\beta} \\ \hat{s}(2)^{\beta} \\ \vdots \\ \hat{s}(m)^{\beta} \end{bmatrix} = \begin{bmatrix} & (m \times n) & \\ & P & \\ & & \end{bmatrix} \begin{bmatrix} v_1 & & 0 \\ & \ddots & \\ 0 & & v_n \end{bmatrix} \begin{bmatrix} d(1) \\ d(2) \\ \vdots \\ d(n) \end{bmatrix} \tag{11}$$

However, note that the optimal production decision for sellers may not coincide with the first-order condition. A seller from region B will prefer not to produce if the fixed cost is high relative to gains from trade. From our assumption on F_m, we know that there is at least one realisation of F for which it is optimal not to produce. However, if the optimal production decision is non-zero, then $s(i) = \hat{s}(i)$.

Substituting (10) into (11), we have

$$\begin{aligned} \begin{bmatrix} \hat{s}(1)^{\beta} \\ \hat{s}(2)^{\beta} \\ \vdots \\ \hat{s}(m)^{\beta} \end{bmatrix} &= \begin{bmatrix} & P & \\ & (m \times n) & \\ & & \end{bmatrix} \begin{bmatrix} v_1 & & \\ & \ddots & \\ & & v_n \end{bmatrix} \begin{bmatrix} d(1) \\ d(2) \\ \vdots \\ d(n) \end{bmatrix} \\ &= \begin{bmatrix} & P & \\ & (m \times n) & \\ & & \end{bmatrix} \begin{bmatrix} & Q & \\ & (n \times m) & \\ & & \end{bmatrix} \begin{bmatrix} s(1) \\ s(2) \\ \vdots \\ s(m) \end{bmatrix} \\ &= \begin{bmatrix} & R & \\ & (m \times m) & \\ & & \end{bmatrix} \begin{bmatrix} s(1) \\ s(2) \\ \vdots \\ s(m) \end{bmatrix} \end{aligned}$$

Before solving for the equilibrium supplies, let us solve for a related system

$$\begin{bmatrix} s(1) \\ s(2) \\ \vdots \\ s(m) \end{bmatrix} = \begin{bmatrix} & R & \\ & (m \times m) & \\ & & \end{bmatrix} \begin{bmatrix} s(1) \\ s(2) \\ \vdots \\ s(m) \end{bmatrix} \tag{12}$$

where we have removed the exponent β from the left-hand side. The matrix R is assumed to be irreducible. We have

Lemma 1 *Any solution to (12) is a constant function.*

Proof. *Since R is irreducible,*

$$s = Rs = R^2 s = \cdots = R^\infty s$$

where R^∞ is the matrix whose rows are identical, and given by the stationary distribution associated with the Markov chain with transition matrix R. Since each row of R^∞ is identical, s is constant. ■

Theorem 2 *For any profile of fixed costs, there is $\beta^* > 1$ such that for $\beta < \beta^*$, the unique equilibrium outcome is*

$$\begin{bmatrix} s(1) \\ s(2) \\ \vdots \\ s(m) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

Proof. *First, note that $s = 0$ is an equilibrium. If no-one produces, then buyers will not come to market. Conversely, when buyers do not come to market, no-one produces. We need to show that there is no equilibrium with positive production. From the benchmark lemma, we know that when $\beta = 1$, any solution to equilibrium supply is a constant function. However, since*

$$s(m) = 0$$

the only solution is the zero function. The equilibrium supply is a continuous function of β. As $\beta \to 1$ from above, the first-order conditions for supply approach zero from above. For given fixed cost F_i, when the amount of sales becomes small enough, the seller prefers not to produce at all. Hence, for β close to 1, the only equilibrium is when no-one produces. ■

In constrast to the drastic, inefficient outcome with decentralised trade, the existence of a deposit bank will enable efficient production and exchange. With the deposit bank facilitating payments, the game boils down to one with common knowledge, and hence there is an equilibrium where producers produce positive quantities in some states.

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