European
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EHES Working Paper | No. 170 | November 2019

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An updated version of this paper has been published as:

The vagaries of the sea: evidence on the real effects of money from maritime disasters in the Spanish Empire. Review of Economics and Statistics, forthcoming

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The vagaries of the sea: evidence on the real effects of money from maritime disasters in the Spanish Empire

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Abstract

We exploit a recurring natural experiment to identify the effects of money supply shocks: maritime disasters in the Spanish Empire (1531-1810) that resulted in the loss of substantial amounts of monetary silver. A one percentage point reduction in the money growth rate caused a 1.3% drop in real output that persisted for several years. The empirical evidence highlights nominal rigidities and credit frictions as the primary monetary transmission channels. Our model of the Spanish economy confirms that each of these two channels explain about half of the initial output response, with the credit channel accounting for much of its persistence.

JEL Codes: E43, E44, E52, N10, N13

Keywords: Monetary Shocks, Natural Experiment, Nominal Rigidity, Financial Accelerator, DSGE, Minimum-Distance Estimation, Local Projection

[*] A previous version of this paper circulated under the title "The real effects of money supply shocks: Evidence from maritime disasters in the Spanish Empire". The authors wish to thank Guido Ascari, Adrian Auclert, Jeremy Baskes, David Chilosi, Leonor Costa, Casper de Vries, Barry Eichengreen, Nicholas J. Mayhew, Carlos Alvarez Nogal, Pilar Nogues-Marco, Gary Richardson, Rafaelle Rossi, Nathan Sussman, Rick van der Ploeg, Akos Valentinyi, François R. Velde, Chris Wallace, and Nikolaus Wolf for helpful comments. We are very grateful to Noel Johnson, Leandro Prados de la Escosura and Kivanç Karaman for sharing their data with us. Any remaining errors are our own.

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1. Introduction

The Columbian voyage of 1492 marked the beginning of three centuries in which vast amounts of monetary silver were shipped from America to Spain. During that time, Spain's money supply was subjected to the vagaries of the sea: maritime disasters that resulted in the loss of silver-laden ships gave rise to random contractions in Spain's money supply. We exploit this repeated natural experiment to obtain well-identified estimates of the causal effects of money supply shocks on the economy.

To conduct the empirical analysis, we compile a novel dataset of maritime disasters in the Spanish Empire. For each maritime disaster we collect data on the quantity of silver lost, the cause of the disaster, and the quantity of silver that was salvaged in the aftermath of the event. Most maritime disasters were caused by bad weather, especially hurricanes. When expressed as a fraction of the Spanish money supply, silver losses constituted shocks to the money growth rate.

We find that a 1 percentage point reduction in the money growth rate led to a 1.3% drop in real output that persisted for several years. A transmission channel analysis reveals that this non-neutrality result was associated with a slow adjustment of nominal variables and a tightening of credit markets: Prices fell by around 1%, but only with a lag, and lending rates temporarily increased by 1.5 percentage points. We show that other channels of monetary transmission, such as the Crown's finances and changes in the silver content of the unit of account, showed few signs of activity.

We arrive at these results by using our money shock measure to estimate impulse response functions (IRFs). We do so using local projections and autoregressive models. The resulting IRFs compare the trajectories of macroeconomic variables across years that are exposed to exogenous variation in money supply growth rates. Clean identification requires that the money shock is not correlated with other shocks – neither contemporaneously, nor across time. We present evidence in support of this assumption using several robustness checks and diagnostic statistics (including pre-event analyses and placebo tests).

To assess quantitatively how much of the short-run non-neutrality result can be explained by nominal rigidities and credit frictions we build and estimate a DSGE model of the early modern Spanish economy. The model is estimated using a minimum distance estimator that matches the model's IRFs to the reduced-form empirical IRFs. We then use the structural underpinnings of the model IRFs to decompose the short-run response of real output into the contributions of nominal rigidities and credit frictions.

The structural analysis confirms that nominal rigidities and credit frictions were sufficiently powerful to account for most of the non-neutrality result, leaving little to explain for other monetary transmission channels. We find that half of the on-impact response of real output is explained by nominal rigidities, and the other half by credit frictions. The latter also explain much of the persistence of the real output response. Whereas the transmission through nominal rigidities has largely abated after three years, credit frictions continued to exert downward pressure on output.

The first contribution of this paper is to provide well-identified, reduced-form estimates of the causal effects of money supply shocks. In doing so, we add to the body of evidence that sheds light on the interaction between money and the real economy based on historical monetary experiments (Velde, 2009; Palma, 2019). Our identification strategy in particular is related to Koudijs (2015, 2016), who exploits weather-induced interruptions of ship traffic across the English Channel in the early modern period to analyze how information flows affect stock market valuations. The strength of the experimental approach is that it requires few assumptions to identify causal effects. This luxury is seldom provided to studies of monetary policy, which usually are more demanding in this respect. Methodological examples include structural VARs (Christiano et al., 1999; Uhlig, 2005; Bernanke et al., 2005; Coibion, 2012), estimated DSGE models (Ireland, 1997, 2003; Smets and Wouters, 2007), instrumental variable strategies (Jordà et al., 2019), which are often applied in combination with high frequency data, (Gertler and Karadi, 2015; Miranda-Agrippino and Ricco, 2018; Nakamura and Steinsson, 2018a), and narrative approaches to identifying monetary shocks (Friedman and Schwartz, 1963; Romer and Romer, 1989, 2004; Cloyne and Hürtgen, 2016). Comprehensive overviews of common identification methods in macroeconomics are provided by Ramey (2016) and Nakamura and Steinsson (2018b).

The second contribution of this paper is to trace the real effects of money through its various transmission channels (e.g. Mishkin, 1995; Kuttner and Mosser, 2002; Auclert, 2019). In this regard, our findings highlight the relevance of price rigidities (Calvo, 1983; Christiano et al., 2005; Nakamura and Steinsson, 2013; Gorodnichenko et al., 2018), and credit frictions (Kiyotaki and Moore, 1997; Carlstrom and Fuerst, 1997; Bernanke et al., 1999). That these two channels – so familiar to economists today – were already present in the early modern period underscores their importance.

The remainder of the paper is structured as follows. Section 2 introduces the data and describes our reduced-form causal analysis. The model economy and the structural analysis of the short-run non-neutrality result are described in Section 3. Those monetary transmission channels that our analysis reveals as unimportant are discussed in Section 4. Section 5 concludes.

2. The causal effects of money supply shocks

2.1. Money and precious metal inflows in early modern Spain

Money in early modern Spain consisted mainly of coins made of precious metals – above all silver (Palma, 2019).[1] While other varieties of money existed, precious metal coins were more widely accepted than their surrogates, such as banknotes or bills of exchange (Nightingale, 1990). As late as 1875, gold and silver made up 85% of the Spanish money supply (Tortella et al., 2013, p.78). Our analysis therefore focuses on gold and silver coins, which we interchangeably name "money" in the following.

Spain's money supply was heavily influenced by the inflow of precious metals from America. Annual Atlantic inflows were large, ranging from less than 1% to almost 20% of the Spanish money stock. Precious metal inflows primarily constituted remittances, transfers of incomes from abroad, and capital inflows.[2] Compared to fiat money, commodity money possesses higher intrinsic value, either because the commodity delivers direct utility (e.g. when used ornamentally) or because it enters the economy's production function (e.g. when producing silverware). Thus, whenever the monetary value of a precious metal falls below its intrinsic value, coins will be melted down and sold on the commodity market. However, there is little concern that silver and gold affected the Spanish economy as production factors rather than as money, because the vast majority of precious metals already arrived in coined form (de Paula Perez Sindreau, 2016; Costa et al., 2013, p.63).

While public authorities guaranteed the silver content of the coinage in imperial mints, precious metal mines were owned and run by private entrepreneurs (Walton, 1994, p. 20), and more than 80% of precious metal remittances from the colonies were privately owned (García-Baquero González, 2003; Costa et al., forthcoming).[3] Thus, maritime disasters led to the loss of money that the private sector thought it possessed. The annual arrival of treasure ships was scheduled in advance (Chaunu and Chaunu, 1955), and publicly available prognoses of how much precious metals would arrive were on average correct (Palma, 2019). Therefore, maritime losses of precious metals can be viewed as negative shocks to the growth rate of the Spanish money supply.

[1] Copper coins also played a role for domestic transactions, but they could only be used for small transactions (Sargent and Velde, 2002), and their prominence fluctuated over time (Motomura, 1994). Only for a few decades after 1619 did copper coins make up a large share of the Spanish money stock (Velde and Weber, 2000). Gold coins, by contrast, were issued in large denominations.

[2] Less than a third of precious metal inflows constituted payment for Spanish exports (based on total export values from Phillips, 1990, p.82). Furthermore, the available Spanish export data (Esteban, 1981) exhibits no correlation with precious metal inflows (Table B.1 in the Appendix). Also note that because the typical roundtrip from Spain to the colonies took two years, it is possible to account for any export correspondent of money inflows by controlling for lagged indicators of Spanish economic activity.

[3] Only in the late 18th century did the Crown's precious metal share increase above 20%.

2.2. Maritime disasters

We collect data on maritime disasters from a variety of sources. Our main source is Walton (1994), from which we collect the date of a disaster, its cause, the amount of precious metals lost, as well as the amount of precious metals that was salvaged. To obtain a more complete description of maritime disasters we complement this data with information from catalogs of sunken treasure ships (e.g. Potter, 1972; Marx, 1987). We restrict our data collection to maritime disasters that resulted in the loss of monetary gold and silver that was destined for Spain. The resulting list of events is described in Table 1. A detailed listing of the sources for each individual disaster event is provided in Table A.1 in the Appendix.

In total we observe maritime disasters that produced money shocks to the Spanish economy in 31 out of 280 years. The most frequent cause of maritime disasters was bad weather, such as hurricanes. Navigational errors rank second. A third reason for the loss of silver was capture by privateers. The most notable such event occurred in 1628, when the Spanish fleet, carrying 80 tonnes of silver, was captured by Dutch privateer Piet Heyn. Finally, in three instances silver-laden ships were destroyed in naval combat. In 1804, for example, the Spanish treasure ship Nuestra Señora de las Mercedes was engaged by British naval forces off the coast of Portugal. In the ensuing Battle of Cape Saint Mary the treasure ship exploded, resulting in the loss of more than 100 tonnes of silver.[4]

We argue that these events constitute valid natural experiments. Bad weather as well as navigational errors were unrelated to economic conditions in Spain. Capture and combat admittedly were rooted in interstate conflicts that affected the Spanish economy in more ways than just through the influx of silver. Conditional on that, however, the capture and destruction of silver ships was driven by the random emergence of tactical opportunities, not the evolution of economic variables in Spain. Moreover, our results are robust to excluding conflict-based events. To test whether maritime disasters were in any way related to economic conditions in Spain we also look at the pre-disaster behavior of several economic variables. The pre-event analysis supports the view that the timing of the disasters was unrelated to prior fluctuations in Spanish economic variables (Figure B.6 in the Appendix B). To the extent that silver shipments were insured, many of the providers of this insurance were members of the Spanish merchant community. To Spain as a whole, the fraction of silver losses to money stocks thus constituted money growth shocks.

To arrive at the money growth shock measure, the absolute silver losses from Table 1

[4]While maritime disasters also entailed the loss of non-monetary wealth, such as ships and the lives of sailors, these losses were economically small compared to the monetary loss. A quantitative assessment of non-monetary losses is provided in section 4.

Table 1: Maritime disaster events

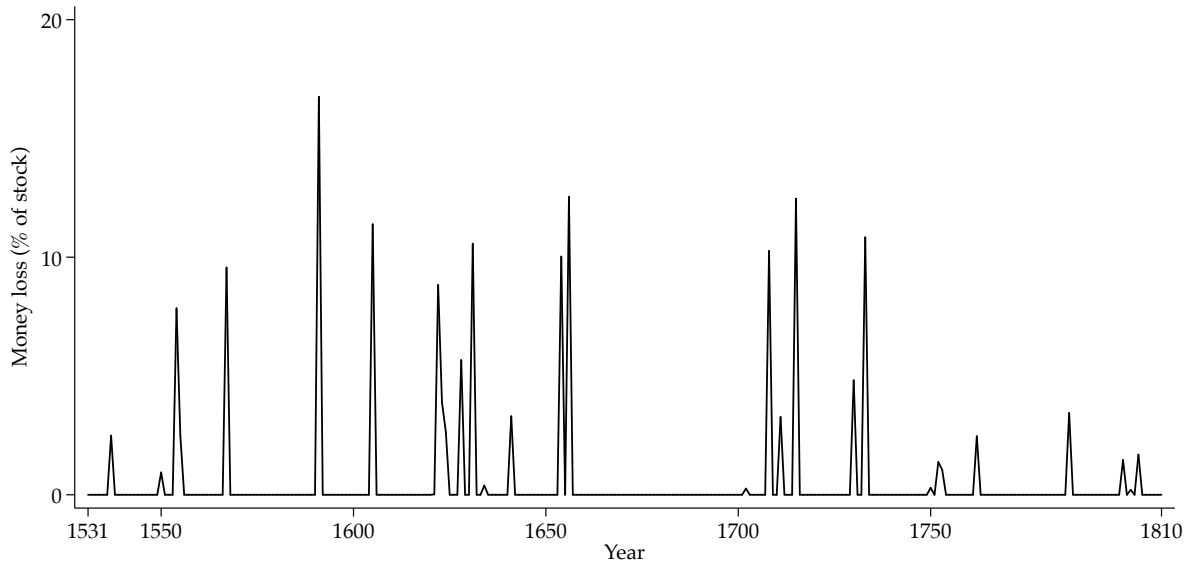
Year	Silver loss	Cause of maritime disaster	Salvaged silver
1502	10,955 kg	weather	0 kg
1537	18,258 kg	capture	N/A
1550	8,079 kg	weather, navigational error	0 kg
1554	73,031 kg	weather	36,516 kg
1555	21,727 kg	weather	8,946 kg
1567	109,547 kg	weather	0 kg
1591	255,610 kg	weather	191,708 kg
1605	204,488 kg	weather	0 kg
1621	382 kg	weather	128 kg
1622	188,951 kg	weather	25,561 kg
1623	76,345 kg	weather	0 kg
1624	51,122 kg	weather	0 kg
1628	111,198 kg	capture, navigational error	8,339 kg
1631	208,410 kg	navigational error, weather	29,988 kg
1634	7,635 kg	navigational error	2,556 kg
1641	76,683 kg	weather	0 kg
1654	255,610 kg	navigational error	89,464 kg
1656	301,620 kg	combat, capture, navigational error	63,903 kg
1702	7,350 kg	combat, capture	0 kg
1708	286,283 kg	combat, capture	0 kg
1711	81,585 kg	weather	43,454 kg
1715	308,382 kg	weather	133,969 kg
1730	138,841 kg	weather	37,215 kg
1733	311,908 kg	weather	308,246 kg
1750	10,321 kg	weather, capture	359 kg
1752	49,620 kg	weather	47,345 kg
1753	37,938 kg	weather	0 kg
1762	99,240 kg	capture	N/A
1786	185,716 kg	navigational error	178,847 kg
1800	95,700 kg	navigational error	43,974 kg
1802	13,671 kg	weather	0 kg
1804	112,896 kg	combat, capture	0 kg

need to be expressed as fractions of the previous year's money stock (a detailed description is provided in Appendix A.2). The resulting shock measure is depicted in Figure 1. On average, maritime disasters resulted in a silver loss that amounted to 5.3% of the Spanish money shock. Shock sizes range from 0.02% to 17%, with a median value of 3.3%.

2.3. Outcome variables

We analyze two types of outcome variables. First, variables that describe real economic activity. Second, variables that describe the monetary transmission channels that are highlighted in the literature on the early modern Spanish economy. With regard to the first, economic historians have recently rebuilt early modern historical national accounts for many countries using large amounts of data from sources such as probate inventories

Figure 1: Monetary shock measure



and the account books of monasteries, universities, and hospitals.[5] For Spain, we can thus use the annual real output data that Álvarez-Nogal and Prados de la Escosura (2013) have compiled for our sample period.[6]

We use different time series to throw light on the role of various transmission channels. To get an idea of how nominal variables reacted to money supply shocks we rely on the consumer price and wage series that have been compiled by Álvarez-Nogal and Prados de la Escosura (2013). Obtaining time series on variables that convey information about credit market conditions, such as lending rates, is more difficult. Usury laws led to the hiding of interest payments. Additionally, many original sources were lost and no longer exist (Homer and Sylla, 1991; Pike, 1966, p. vi). Fortunately, lending rates left their mark in exchange rates – more particularly in the prices of bills of exchange that were systematically quoted in financial markets throughout Europe.

The exchange rate embodied in a bill of exchange differs from the spot exchange rate in that it describes the amount of currency to be delivered at one place today in exchange for another currency at another place at a later date. This time delay means that bills of exchange combined a spot exchange transaction with a lending transaction. In fact, against the background of the prohibition of many types of lending through usury laws, bills of exchange became Europe's dominant lending instrument. They allowed lending rates to be hidden within what on the surface was a foreign exchange contract (de Malynes, 1601; de Roover, 1967; Flandreau et al., 2009).

[5] For details about the exact reconstruction procedures see de Jong and Palma (2018). See Palma (forthcoming) for details about the sources typically used.

[6] A more detailed discussion of this data is provided in Appendix A.4.

Extensive datasets of early modern bill of exchange quotations have been compiled (Schneider et al., 1994, 1992; Denzel, 2010), enabling us to throw light on the fluctuations in lending rates that Spanish merchants faced. Appendix A.3 provides a detailed description of how we use bill of exchange prices to infer the behavior of lending rates in Spain.[7]

2.4. Econometric method

We use local projections (Jordà, 2005) to estimate impulse response functions (IRFs) for horizons $h = 0, ..., H$:

$$(Y_{t+h} - Y_{t-1})/Y_{t-1} = \alpha_h + \beta_h S_t + \gamma_h X_t + u_{t+h} \tag{1}$$

where Y_t is the outcome of interest – real GDP, CPI, wages and interest rates. u_{t+h} denotes the horizon-specific error term. S_t is the money shock measure. X_t is a vector of control variables. The estimated β_h coefficients describe the cumulative response of the outcome variable to a monetary shock: β_0 captures the cumulative response between period $t-1$ and t, β_1 captures the cumulative response between period $t-1$ and $t+1$, and so on.

The baseline specification includes L lags, H leads, and the contemporaneous values of the following exogenous control variables: the money shock measure S_t, the amount of money that was salvaged after a maritime disaster (% of stock), silver lost due to capture (% of stock), Spanish temperature, and indicators of the number of military conflicts that Spain was involved in (based on the historical conflict catalogue by Brecke, 1999).[8] Our baseline specification includes lags of the following endogenous controls: the dependent variable's growth rate, price level growth, wage growth, real GDP growth, and the money stock growth rate.[9] While we saturate our baseline specification with a rich set of control variables, the next section lists various robustness checks that also document the robustness of our results to more parsimonious specifications.[10]

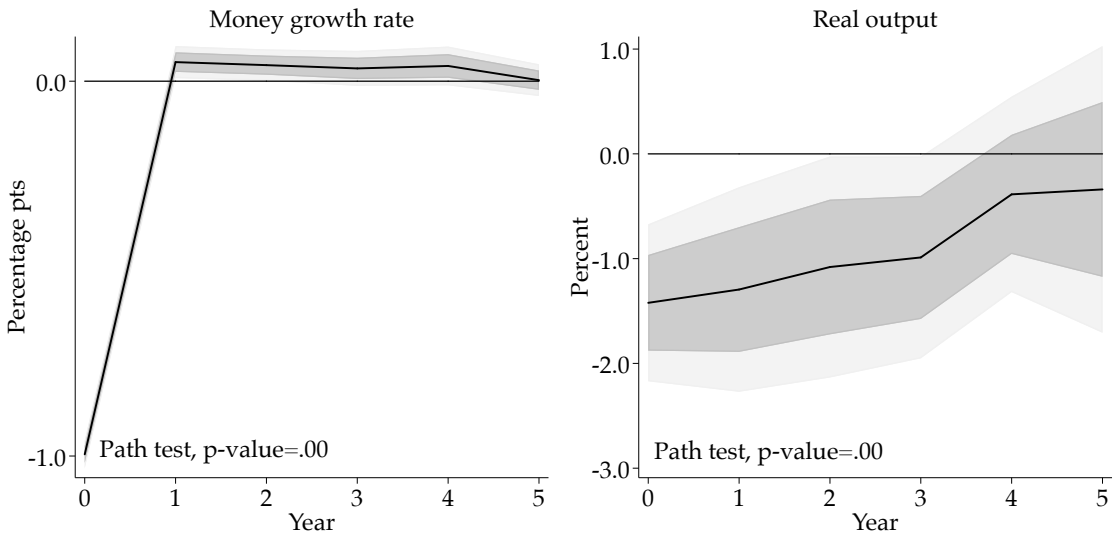
[7] The calculated interest rate fluctuations are best regarded as fluctuations in risky lending rates, rather than risk-free rates. Merchants who used bills of exchange were typically active in long-distance trade, which was a fundamentally risky business. Uncertainty sprang from various sources, such as the delay in information about market prices, and the damage or loss of goods in transport (Baskes, 2013, p.8). Seville, for example, one of the Spanish cities most involved in the Spanish colonial trade, was considered an "unsafe place" by contemporaries in this regard (Lapeyre, 1955, p.267).

[8] See Stock and Watson (2018) on the advantages of including leading exogenous controls.

[9] The sudden introduction of large amounts of copper coins led to a flight to silver and violent swings in the exchange rate between copper and silver coins in 1625-1627 and again in 1640-1642 (Hamilton, 1934, p.95). Our results are robust to allowing for the effects of money shocks to differ for these periods.

[10] Saturation with control variables serves to increase estimate robustness and precision. Precision increases to the extent that additional control variables can account for the outcome variable of interest. For example, in the parsimonious specification the error terms, u_{t+h}, are likely to be correlated with the

Figure 2: Real response to a negative 1 percentage point money growth shock



Notes: Gray areas – 1 standard deviation and 90% confidence bands. Two-sided path test for equality of response to 0 across all horizons – Cross-horizon H0: $\beta_h = 0 \; \forall \; h = 1, ..., 5$.

For our baseline specification we set $L = 4$. For each estimated IRF we report point-wise confidence bands, as well as the result of a joint cross-horizon test that indicates whether the mean IRF estimate as a whole differs from zero.

2.5. The real effect of money supply shocks

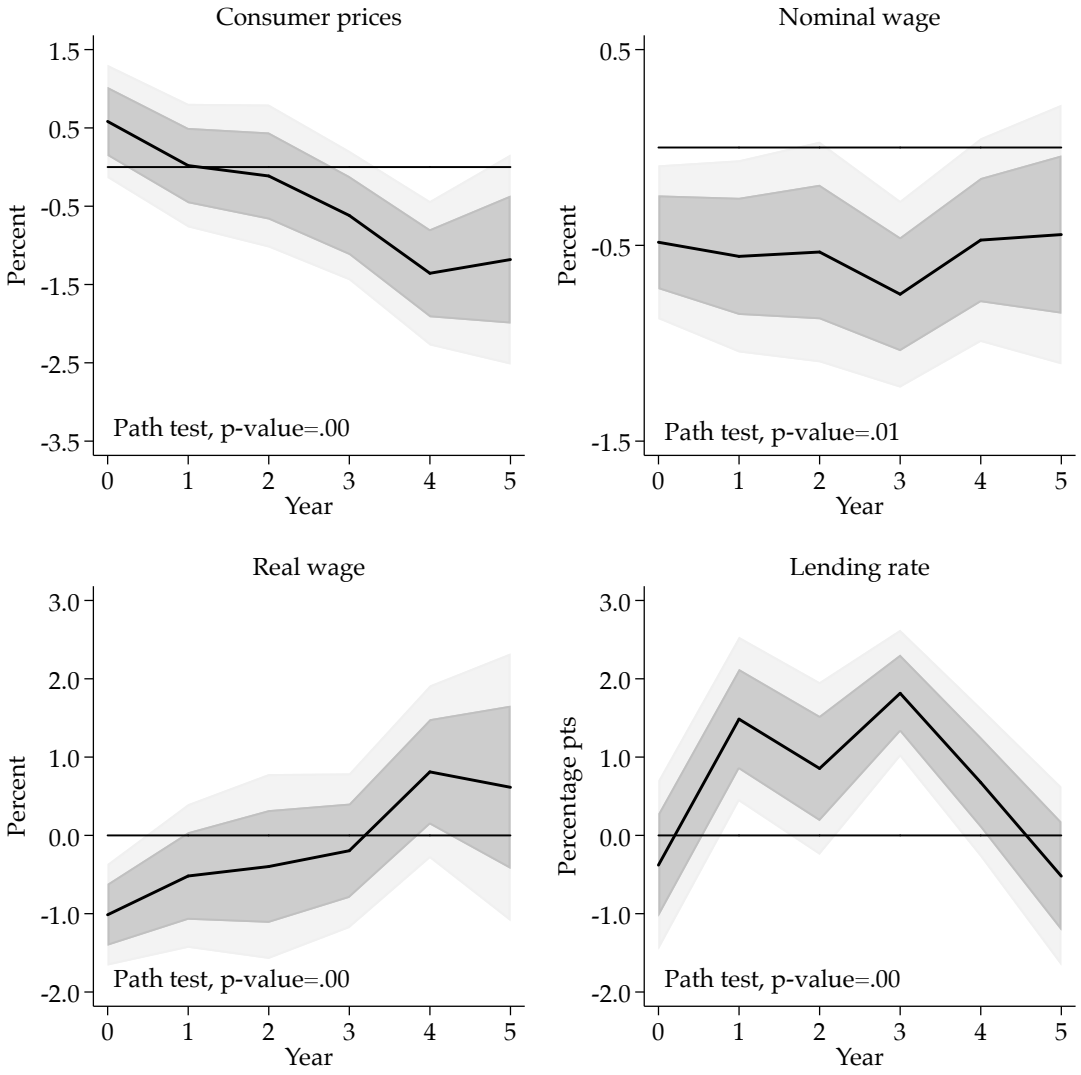
What was the real effect of money on the Spanish economy? Figure 2 shows the answer provided by our IRF estimates. First, the left panel of the figure describes the monetary shock that hits the Spanish economy: a 1 percentage point reduction in the money growth rate. This is equivalent to a 1% reduction in the money stock. In response to this money supply shock Spanish output drops by 1.3% on impact. This drop in output persists for several years. The cross-horizon path test clearly rejects the null of no-response for the whole IRF.

2.6. Monetary transmission channels

There existed several potential monetary transmission channels in the early modern Spanish economy. Here we take a look at the data for indications of whether a channel was

Spanish weather, given the importance of agriculture in the early modern Spanish economy. Controlling for the weather reduces the variance of the error term and thus improves the precision of the IRF estimates. Robustness increases, where control variables safeguard our identification strategy. For example, money shocks associated with naval combat and capture by privateers were rooted in interstate conflicts. Conditional on that, however, the associated silver losses were orthogonal to the Spanish economy.

Figure 3: Transmission channels: responses to negative 1 ppt money growth shock



Notes: Gray areas – 1 standard deviation and 90% confidence bands. Two-sided path test for equality of response to 0 across all horizons – Cross-horizon H0: $\beta_h = 0 \; \forall \; h = 1, ..., 5$.

active or not. Our selection of transmission channels aims for comprehensiveness and is grounded in a careful reading of the historical literature on early modern Spain and its monetary system. Overall we analyze four different transmission channels. In this section we discuss only those two channels which the data indicate were important, and which we thus subject to a structural analysis in section 3. The other two transmission channels are discussed in section 4.

Nominal price and wage rigidities

There exists little consensus on how flexible wages were in early modern Spain.[11] However, evidence suggests that at least some wages changed frequently. Laborers' contracts, for example, lasted from a single day to several months. Contract duration was typically determined by the duration of a seasonal task, such as the grain harvest. Thus, at an annual frequency, many wages were flexible.[12]

An important source of nominal price rigidity in early modern Spain were guilds. They were prevalent in the urban manufacturing and service sectors, but they also could be found in the primary sector, and among rural artisans (Ogilvie, 2011, p.19). As producers of differentiated products, guilds could set collective monopoly prices for the output of their members. If large enough, or if in possession of a chartered right to be the exclusive buyer of a particular industry's output (Ogilvie, 2011, p.33), guilds also could set price ceilings on the raw materials they purchased from their suppliers (Ogilvie, 2014).

A look at the IRFs in Figure 3 shows that consumer prices indeed reacted sluggishly in response to money supply shocks. Only after three years did the CPI fall by 1%, and prices continued to fall until year four. This renders price rigidity a prime suspect in our search for the monetary transmission channels behind the short-run non-neutrality result. By contrast, nominal wages quickly fell between 0.5% and 1%. On impact, falling nominal wages translated into falling real wages, but after that real wages reflated in line with consumer price deflation.

External financing and credit frictions

Despite the prohibition of many forms of interest rates, external financing played an important role in early modern economies. Table 2 displays asset-to-net worth ratios for European merchants between 1485 and 1700. The country-means range from 1.54, for England around 1500, to 2.65, for the Netherlands in the early 17th century. The suppliers of credit were ecclesiastical institutions, nobles, wealthy merchants/merchant-bankers and others (Pike, 1965; Milhaud, 2015). Lenders were perceptive of the riskiness of borrowers' financial position, and charged lending rates accordingly (Carrasco González, 1996, ch.2).

External financing also played a role in the Spanish colonial trade (Pike, 1962; Bernal and Ruiz, 1992; Carrasco González, 1996, p.160). That merchants and banks became busy "withdrawing and assigning", "charging and discharging" accounts as soon as a silver fleet had arrived demonstrates as much (de Mercado, 1587, p. 170). This activity was the

[11] Even in rural areas, where wages made up only part of household income (García Sanz, 1981), wage income was common. Despite widely spread land ownership, the majority of many farming communities consisted of landless day laborers (Phillips, 1987, p.535).

[12] Wages of day laborers in early modern Spain were at times regulated by public authorities, but regulations were often not enforced in practice (Vassberg, 1996, p.70).

Table 2: Early modern asset-to-net worth ratios

Country	Time	Asset-to-net worth ratio			Source
		Low	High	Point estimate	
England	1485–1560	1.04	3.79	1.54	*Oldland (2010)*
Portugal	16th century	2	3	2.5	*Costa (1997)*
Netherlands	1611			2.65	*Gelderblom and Jonker (2004)*
Cadiz	1680–1700	1.13	2.83	2.26	*Carrasco González (1996)*
Spain	1747			2.85	*Bernal and Ruiz (1992)*

Notes: The point estimates are either directly taken from the source or are calculated as the mean of a range of asset-to-net worth ratios. Oldland (2010) data based on probate inventory of 13 merchants. Gelderblom and Jonker (2004) ratio based on sum of deposits and bonds over net worth for one merchant. Bernal and Ruiz (1992, pp.369-370) based on individual merchant company's balance sheet, treating credit-financed owner contributions as equity. Carrasco González (1996) data on loans in Cadiz as a fraction of exports from Cadiz to colonies, assuming the value of Cadiz exports proxies Cadiz merchant assets. Spanish exports calculated as 0.27 times Spanish imports according to the Spanish export-import ratio for the late 17th century (Phillips, 1990, pp.95-96). Spanish imports calculated as 1.25 times treasure imports corresponding to the 80% import share of treasure (García-Baquero González, 2003). Cadiz exports calculated as 0.85 times Spanish exports according to the share of ships sailing from and to the colonies touching Cadiz (Phillips, 1990, p.96).

complement to the loans that had been taken out by merchants to acquire merchandise, or by skippers to outfit their ships (Pike, 1966, p.75).[13] The data for Cadiz between 1680 and 1700 suggests that merchant asset-to-net worth ratios fluctuated between 1.13 and 2.83. A snapshot of a Spanish merchant company balance sheet in 1747 shows a asset-to-net worth ratio of 2.85. For those merchants who were the owners of the silver that never arrived, the persistent money stock loss depicted in Figure 2 constituted a persistent negative net worth shock. In an environment characterized by credit frictions and nominal rigidities, such a net worth deterioration can give rise to an increase in the cost of external finance and thus put downward pressure on investment.[14]

Indeed, we find that in the short-run a -1% money shock led to an increase in lending rates by 1-2 percentage points (Figure 3). The lending rate response exhibits a lagged reaction, with lending rates peaking one year after the shock. One likely explanation for this is that the lending rate series is constructed on the basis of bill of exchange prices that were quoted in financial centers across Europe (e.g. Amsterdam, and London). The spatial distance between these financial centers and Spain opens the door for information lags. Thus, although lending rates in Spain may well have reacted on impact, this may not be reflected in our data due to the time it took for news to travel through Europe. This interpretation finds support in the historical literature on the Atlantic economy, which

[13] While the ship often was owned capital, the cargo, as well as weapons and food for sailors were financed through credit. See Price (1989) for a related account of English merchant financing during the early modern period.

[14] Phillips (1987, p.540), for example, notes that part of the investment in the Spanish industrial sector was directly financed out of profits that were generated abroad.

suggests that even delays in the arrival of silver shipments caused the Sevillian money market to tighten up immediately (Pike, 1966, p.87). We are therefore inclined to discount the lacking on-impact response of lending rates as an artifact of data construction.[15]

As a placebo test we also estimated IRFs for the lending rates in several other Western European financial centers. The results show that lending rates in all Spanish cities increased markedly, while this is not the case for other European cities (Figure B.7 in the Appendix B).

To sum up, a 1 percentage point reduction in the money growth rate led to a 1.3% drop in real output that persisted for several years. The real output drop was accompanied by tighter credit markets and nominal rigidities. These results are robust to various relevant alterations of the econometric model and shock definition (Appendix B). A more parsimonious specification that includes only the contemporaneous silver shock regressors and lags of the dependent variable results in similar IRFs (Figure B.1). The results are also robust to excluding money shocks that were rooted in international conflict (capture and combat events) from the analysis (Figure B.2). The same holds for excluding years in which copper coins (vellón) made up a large fraction of the Spanish money stock (Velde and Weber, 2000) (Figure B.4). We furthermore obtain very similar results when we estimate impulse response functions through autoregressive distributed lag (ARDL) models as in Romer and Romer (2004) and Cloyne and Hürtgen (2016) (Figure B.5).

While this reduced-form evidence provides some insights into the reaction of nominal variables and credit markets to money shocks, it does not allow us to quantitatively assess the importance of different monetary transmission channels. This is the purpose of the following section.

3. Structural analysis of monetary transmission channels

We round out our inquiry into the channels of monetary transmission with a structural analysis. We use a carefully calibrated and estimated model of the early modern Spanish economy to answer the following two questions: First, how much of our overall non-neutrality result can plausibly be explained by nominal rigidities and credit frictions? Second, what are the respective contributions of these two channels? Before assessing transmission channel strength, we shortly outline the model's key features, as well as its calibration and estimation. A detailed description of the model is provided in Appendix C.

[15] Another possible interpretation is that interest rates were indeed rigid in a similar way as nominal wages or prices. This possibility is explored in Appendix D.2.

3.1. The model

The model is a stylized DSGE model of the early modern Spanish economy. It features nominal rigidities, credit frictions, and a regular stream of money inflows that resembles the arrival of silver shipments.[16]

We characterize the **household**'s objective by an additively separable CRRA utility function. Households derive utility from consumption, c_t, real money holdings, $m_t = M_t/P_t$, and labor, l_t:

$$U(c_t, m_t, l_t) = \frac{c_t^{1-\sigma}}{1-\sigma} + \zeta \frac{m_t^{1-\psi}}{1-\psi} - \xi \frac{l_t^{1+\upsilon}}{1+\upsilon}.$$

σ, ψ, and υ are the inverses of the elasticity of intertemporal consumption substitution, the interest elasticity of money demand, and the Frisch elasticity of labor supply, respectively. ζ and ξ are positive parameters that weigh the utility of real money holdings and labor.[17]

The household derives income from wage labor, $W_t l_t$, last period's money savings, M_{t-1}, last period's interest-bearing savings, here modelled as a one-period risk-free nominal deposit, $R_{t-1}D_{t-1}$, and a lump-sum dividend payment from the economy's production sector and guilds, Ω_t. To maximize expected life-time utility, this income is optimally allocated to consumption, $P_t c_t$, money holdings, M_t, and new deposits D_t.[18]

The **production sector** is made up of four different agents: capital goods producers, entrepreneurs, financial intermediaries, and retailers. This layering of the production sector ensures that each agent faces a comparatively simple decision problem, which in turn ensures the model's tractability (Bernanke et al., 1999). The four agents can be thought of as representing the producers, merchants, and merchant-bankers of early modern Spain.

Capital goods producers use investment inputs composed of final goods, i_t, to produce new capital, Δ_t^k. In doing so they incur a resource cost, $\Psi\left(\frac{i_t}{k_{t-1}}\right) k_{t-1}$.[19] The capital adjustment cost function, $\Psi(\cdot)$, pins down the economy's capital supply elasticity, and thus the sensitivity of investment with respect to various shocks. The produced capital is sold to entrepreneurs on a competitive market and depreciates with rate δ. Taking the nominal price for capital, Q_t, as given, capital goods producers maximize their period profits by choosing the amount of investment inputs.

[16] A model with nominal rigidities but no credit frictions delivers similar results regarding the explanatory power of nominal rigidities for the overall output response.

[17] According to this money-in-utility approach the utility of holding money is separable from the utility of consumption. Absent credit frictions, this assumes that money shocks have no impact on real variables, unless nominal frictions prevent prices, and thus real money holdings, from adjusting.

[18] Note that households do not receive any silver inflows. This is because we classify households that participated in the transatlantic colonial exchange as entrepreneurs in the model.

[19] We assume that in steady state $\Psi\left(\frac{i}{k}\right) = 0$.

Entrepreneurs are risk-neutral producers that use a Cobb-Douglas production function to turn pre-existing capital, k_{t-1}, and newly hired labor, $\tilde{l}_t$, into intermediate goods, y_t.[20] Entrepreneurial production is subject to an idiosyncratic productivity shock, ω_t. Taking the market price for their output as given, entrepreneurs choose capital and labor to maximize their net worth, N_t. The purchase of capital k_{t-1} is partly financed internally, out of the entrepreneur's net worth N_{t-1}, and partly externally, through credit B_{t-1} obtained from financial intermediaries: $Q_{t-1}k_{t-1} = B_{t-1} + N_{t-1}$. The cost of credit is described by the average nominal lending rate $\tilde{R}^k_{t-1}$. Produced intermediate goods are sold on a competitive market at price $\tilde{P}_t$. Profits and money inflows accrue to the entrepreneur's net worth. Only a random fraction $\gamma \in (0,1)$ of entrepreneurs carry over their accumulated net worth to the next period and continue with their business. The rest exit, and consume their net worth.[21] In our calibration, the entrepreneurial survival rate, γ, pins down the steady state asset-to-net worth ratio of entrepreneurs.

Financial intermediaries channel the household's non-money savings to entrepreneurs as loans. Following Bernanke et al. (1999), a state verification problem gives rise to a positive external finance premium $\tilde{R}^k_t/R_t > 1$. In particular, as a consequence of **credit frictions**, external financing is more expensive than internal financing, and the external finance premium is an increases function of entrepreneur leverage:

$$\frac{\tilde{R}^k_t}{R_t} = \Lambda\left(\frac{Q_t k_t}{N_t}\right), \tag{2}$$

where $\Lambda(\cdot)$ denotes a function that increases in its argument.

Goods **price rigidity** enters the model through retailers (final goods producers), who differentiate the intermediate goods and sell final goods on a monopolistically competitive market. Retailers maximize their profits by setting prices, subject to the demand for final goods. Analogously to the nominal friction on the labor market, each period only a fraction, $(1-\theta_p)$, of retailers can re-optimize their prices. The rest increases their prices by the steady state inflation rate.[22] Retailer profits are distributed to households at the end of the period as a lump sum payment.

Wage rigidity enters the model through guilds, which differentiate the households' labor supply and offer it on a monopolistically competitive labor market. They thus behave similarly to labor unions in Schmitt-Grohé and Uribe (2005).[23] In the model,

[20] $\tilde{l}_t$ is a Dixit-Stiglitz aggregator of the variety of labor offered by guilds: $\tilde{l}_t = \left(\int_0^1 l_t(i)^{\frac{\mu_w-1}{\mu_w}} \mathrm{d}i\right)^{\frac{\mu_w}{\mu_w-1}}$.

[21] The purpose of assuming a finite life span is to prevent entrepreneurs from accumulating enough net worth to self-finance capital purchases.

[22] Results are robust to introducing price backward indexation (Appendix D.2).

[23] In its log-linearized version, this approach to modeling guilds/labor unions is isomorphic to the alternative modeling strategy introduced by Erceg et al. (2000), according to which each household is a

guilds maximize their profits by setting wages. Similar to the modeling of price rigidity in Calvo (1983) and Yun (1996), wage rigidity arises from the fact that in each period only a fraction, $(1-\theta_w)$, of guilds can reset their wages; the rest simply increases their wage according to the steady state inflation rate.[24] The guilds' profits are forwarded to households as a lump sum transfer.

The **money stock** M^s evolves as

$$M_t^s = M_{t-1}^s(1+g_M)\exp(\epsilon_{M,t}),$$

where g_M is the money stock's trend growth rate. Money inflows, $\Delta_{M,t} = M_t^s - M_{t-1}^s$, are received by entrepreneurs. Money inflows can be lower than expected due to maritime disasters. This exogenous variation forms part of $\epsilon_{M,t}$, an i.i.d. shock with mean zero.[25] Market equilibrium requires that goods, labor, financial, and money markets all clear.

To illustrate the model's monetary transmission mechanisms, consider how a negative money shock impacts the real economy. First, to the extent that rigid nominal prices do not immediately adjust, the household will experience a shortage of real money holdings and consequentially buy fewer consumption goods. Similarly, to the extent that nominal wage rigidity prevents real wages from adjusting the production sector will hire less labor and reduce its output. Second, the negative money shock directly reduces the net worth of the money's owners – the merchants.[26] As a consequence the lending rate increases and merchant demand for inputs decreases. This puts downward pressure on production, wages, and household income. After the initial net worth loss, the economic headwinds described above give rise to a period of low merchant profitability, which hampers the recovery of merchant net worth. In the meantime lending rates remain elevated, and merchant input demand remains depressed.

monopolistic supplier of a differentiated type of labor input.

[24] Our results are robust to introducing backward indexation as in Christiano et al. (2005) (Appendix D.2).

[25] The money growth rate, g_M, and the distribution of the money shock, $\epsilon_{M,t}$, are common knowledge to the whole economy. This corresponds to the fact that contemporaries were aware of the risk of maritime disasters (Baskes, 2013, p.2) and, as evidenced by contemporary newspaper predictions, formed expectations about the amount of precious metals arriving that were on average correct (Palma, 2019).

[26] Note that while a certain amount of risk sharing existed in the form of sea loans and maritime insurance (Baskes, 2013, p.180), the providers of insurance generally were merchants themselves (Bernal and Ruiz (1992), pp.171ff., Costa et al. (2016), p.216, and Baskes (2013), p.10). While maritime insurance was an international business early on, many merchants preferred to insure locally and thus avoid the transaction costs associated with paying a foreign agent to obtain the insurance, as well as conflict resolution and fund recovery in a foreign country (Kingston, 2014). As a consequence, even insured silver losses resulted in a net worth shock to the Spanish merchant community (Alonso, 2015). For the late 18th century some evidence points towards a more substantial role for foreign insurance, but quantitative information about the importance of foreign insurance relative to local insurance is lacking (Baskes, 2016, p.232). Reassuringly, the reported results are robust to excluding the late 18th century from our sample (Figure B.3 in the Appendix).

3.2. Calibration, estimation, and transmission channel strength

We log-linearize the model around its non-stochastic steady state.[27] In the log-linearized model the economy's nominal rigidity is summarized by the slopes of the New Keynesian Phillips curve, $\kappa_p = \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p}$, and its wage equivalent, $\kappa_w = \frac{(1-\theta_w)(1-\beta\theta_w)}{\theta_w}$. Low values for κ_p and κ_w reflect a high degree of nominal rigidity, whereas high values reflect a low degree of nominal rigidity. The parameters are estimated with a minimum distance estimator (MDE) that matches the model IRFs for prices and wages to their empirical counterparts by minimizing the weighted sum of the squared distances between the empirical and model IRFs from $t = 0$ (on impact) to $t = 5$.[28] The weights are the inverses of the empirical IRFs' point-wise variances at each horizon.

Another parameter that is set to match the empirical lending rate response is the elasticity of the external finance premium to changes in merchant leverage, $\Xi = \frac{\Lambda'(\cdot)}{\Lambda(\cdot)}\frac{qk}{n}$. As shown in Figure 3, money losses led to an increase in lending rates, but only with a lag. As previously argued, the construction of the lending rate data is susceptible to the introduction of time lags (see section 2.6). Accordingly, the lack of an on-impact response in the empirical lending rate IRF is best interpreted as an artifact of data construction. We therefore use Ξ to target the lending rate responses from $t = 1$ – one year after the shock – to $t = 5$.[29]

For several parameters, identification from observables is straightforward. We set the production function parameter, α, to 0.25, which results in a labor income share of 75%. This matches the closest available estimate for Spain in 1850 from Prados de la Escosura and Rosés (2009).[30] Corresponding to the same source we set the annual capital depreciation rate, δ, to 1.5% and the capital-to-output ratio, k/y, to 0.8.[31] The low depreciation rate is typical of pre-industrial economies in which slowly depreciating assets, such as dwellings, make up a larger share of the overall capital stock than more quickly depreciating machinery. We use the entrepreneurs' survival rate, γ, to target a steady

[27] The complete log-linearized system of model equations is shown in Appendix C.2.

[28] In the context of DSGE models, see Rotemberg and Woodford (1997), Christiano et al. (2005), and Altig et al. (2011) for applications of VAR-IRF matching estimation, and Jordà and Kozicki (2011) for LP-IRF matching estimation.

[29] An alternative reason for the lagged response could be rigidity in the lending contract itself. Appendix D.2 explores this possibility by estimating a version of the model with rigid lending rates. The lending rate IRF of the adjusted model matches the empirical IRF well. The transmission channel assessment based on the adjusted model yields a quantitatively similar result to the baseline model.

[30] The Spanish labor income share is higher than the U.K. labor income share at the onset of the Industrial Revolution (around 1780), which was 45% according to Stokey (2001). It also exceeds the 38% to 49% range estimate used by Clark (2007) for the U.K. labor income share in the agriculture sector. Our result are similar if we use these lower values for the labor income share.

[31] The capital stock estimates by Prados de la Escosura and Rosés (2009) comprise four categories: residential and nonresidential buildings, transport equipment, as well as machinery and equipment. We calculate the depreciation rate as the average depreciation rate over these four asset categories, using the 1850-1919 depreciation rates weighted with their 1850 stocks.

state entrepreneurial asset-to-net-worth ratio of 2.[32] This is in line with the quantitative information on early modern merchant financing presented earlier (Table 2). We set the steady state money growth rate, g_M, to the mean growth rate of 0.87%. This leads to a corresponding steady state annual gross inflation rate, Π, of 1.0087. The velocity of money is set to 5.45, the mean estimate for our sample. We choose a time discount factor, β, of 0.97 to target a steady state annual nominal gross deposit rate, R, of 1.04. This value corresponds to known level estimates of early modern risk-free rates (Homer and Sylla, 1991; Clark, 2005). The steady state risky rate is set to 1.09, which conforms with the average mid-18th century lending rate in Cadiz (Nogues-Marco, 2011).[33]

For some parameters the historical literature and the data provide less guidance, and we prefer to remain agnostic about their exact values. This is the case for the utility parameters and the capital adjustment cost parameter. We therefore explore the robustness of our results with respect to a wide range of plausible values for these parameters (Appendix D.1). We start by using standard values typically used in macro models today: The elasticity of intertemporal consumption substitution (EIS), $1/\sigma$, is set to 1/2. The interest elasticity of money demand, $1/\psi$, is set to 1, resulting in a log utility function for money holdings, and the Frisch elasticity of labor supply, $1/\upsilon$, is set to 3. Finally, the capital adjustment cost parameter, $\Upsilon = \Psi''(\cdot)\frac{i}{kq}$, is set to 0.6 – the value recently estimated by Christensen and Dib (2008) and Meier and Müller (2006). A lower capital adjustment cost parameter of 0.25, the value used in Bernanke et al. (1999), yields very similar results. So do EIS parameters in the 1 to 1/3 range, interest elasticities of money demand in the 1/0.5 to 1/2 range, and Frisch elasticities in the 2 to 5 range (Appendix D.1).

Table 3 summarizes the baseline calibration, based on which the MDE produces estimates for the nominal rigidity and credit friction parameters. The IRF matching parameters are also reported in the table. The slope of the price inflation equation is 0.08. This value lies at the lower end of the range of present-day estimates (Schorfheide, 2008; Altig et al., 2011),[34] and is lower than the range of 19th century estimates (Chen and Ward, 2019). A comparison with the slope of the wage inflation equation indicates that prices were much more rigid than wages. The estimated wage inflation slope is 6.10, which indicates a high degree of wage flexibility. Finally, Ξ, the sensitivity of the lending rate with respect to merchant leverage equals 0.18, a value that comes close to the annualized estimates by Meier and Müller (2006) and Christensen and Dib (2008).

[32] This implies that entrepreneurs' expected work life spans around 13 years.

[33] Early modern lending rates for households and businesses were lower in some places. For example, Gelderblom and Jonker (2004) report a value of 6.25% for Amsterdam in 1582. The same source, however, puts the Amsterdam return on bonds issued to finance colonial trade at 7% to 8%. The results are very similar when we assume a lower steady state lending rate of 6.25%.

[34] For comparison, we annualize present-day slope estimates through multiplication by 4.

Table 3: Calibrated parameters

Calibrated parameters		Value
$1/\sigma$	elasticity of intertemporal consumption substitution	1/2
$1/\psi$	interest rate elasticity of money demand	1
$1/\upsilon$	Frisch elasticity of labor supply	3
α	production function	0.25
δ	capital depreciation	0.015
γ	survival rate for entrepreneurs	0.92
k/y	steady state capital to output ratio	0.8
g_M	steady state money growth rate	0.01
m/y	inverse steady state velocity of money	1/5.45
R^k	steady state risky interest rate	1.09
β	time discount factor	0.97
Υ	capital adjustment cost parameter	0.6
IRF matching		**Value**
Ξ	leverage elasticity of external finance premium	0.18
κ_p	Slope of price inflation equation	0.08
κ_w	Slope of wage inflation equation	6.10

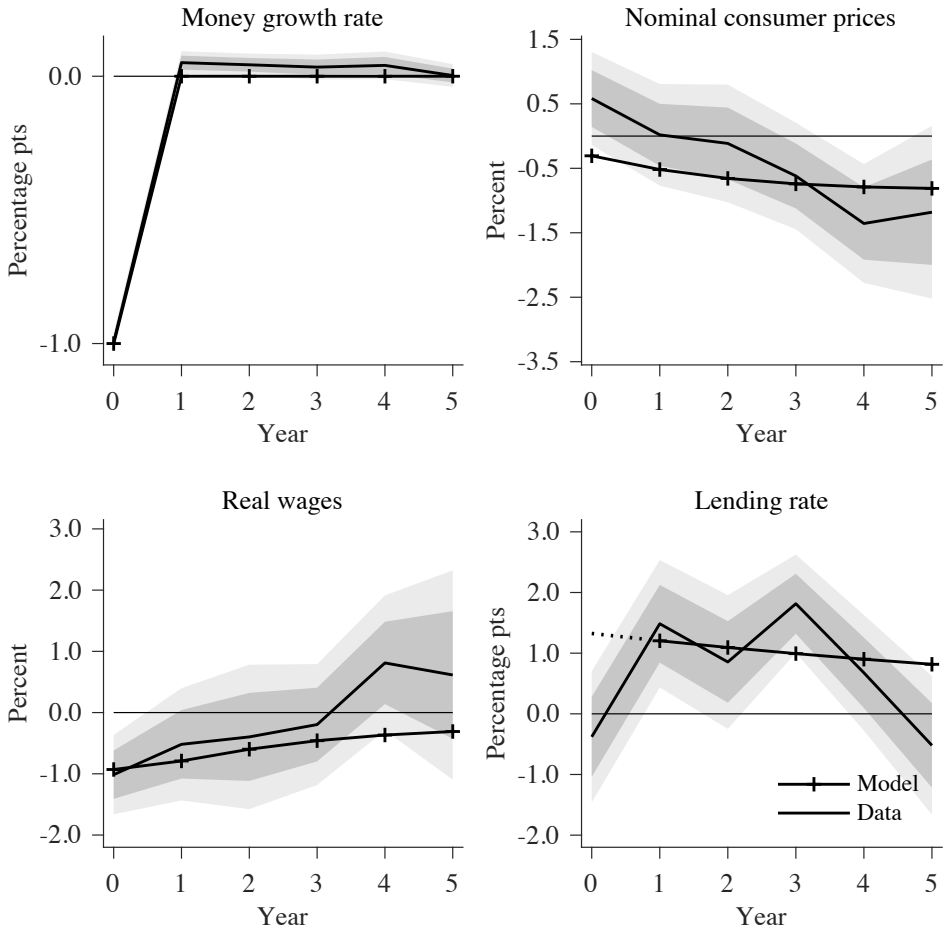
Figure 4 compares the empirical IRFs to the IRFs of the fully parameterized model. The matched model IRFs for prices, wages, and the lending rate share the key features of their empirical counterparts. Based on the parameterized model's account of the early modern Spanish economy, we proceed with the transmission channel analysis.

3.3. Transmission channel strength and decomposition

In this section we analyze transmission channel strength based on the fully parameterized model. First, we assess the combined strength of nominal rigidities and credit frictions. How much of the empirical non-neutrality result can these two channels account for? The left panel of Figure 5 provides the answer. It compares the empirical IRF of real output with its non-targeted model counterpart. Both IRFs exhibit a similar size and persistence. Thus, nominal rigidities and credit frictions in combination are sufficiently powerful to explain much of the real output response. This finding is robust to plausible alterations to the model parameterization (Appenidx D.1). In all cases, the model attributes the bulk of the non-neutrality result to these two transmission channels.

Next, we use the parameterized model to disentangle the relative contributions of nominal rigidities and credit frictions. For this purpose we calculate counterfactual model IRFs for real output, using model calibrations that sequentially shut down the two channels. First, to evaluate the role of the credit friction, we set the elasticity of the risk premium with respect to leverage, Ξ, to zero. This assumes that the risk premium stays at its steady state level and does not vary with entrepreneurial leverage. The resulting

Figure 4: Empirical and model IRFs: responses to negative 1 ppt money growth shock

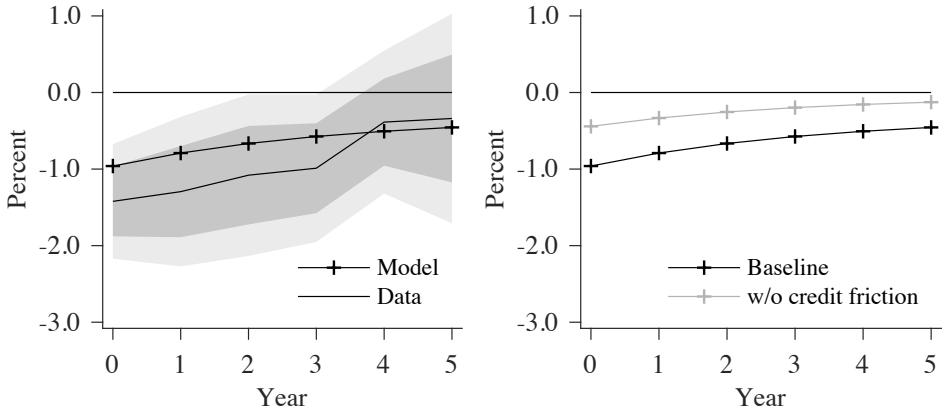


Notes: Solid lines – empirical IRFs. Solid lines with + markers – model IRFs. Gray areas – empirical 1 standard deviation and 90% confidence bands. The dotted line segment for the model's lending rate response indicates that we do not attempt to match the on-impact response of lending rates. This is because the lack of an on-impact response in the empirical lending rate IRF is best interpreted as an artifact of data construction (see section 2.6).

counterfactual output IRF is depicted as the gray line on the right panel of Figure 5. The relative contribution of the credit friction to the real output response is indicated by the area between the gray line and the black line. As can be seen, the credit channel is responsible for around half of the on-impact response. Over time the relative importance of the credit friction increases. After three years it accounts for most of the remaining downward pressure on real output.

The contribution of nominal rigidities to the overall output response is indicated by the area between the dashed IRF and the zero-line. Inflexible prices account for the remaining 50% of the on-impact response of real output. Over time, however, the relative contribution of nominal rigidities declines. After three years, the downward pressure on real output from this channel has largely abated.

Figure 5: Decomposition of the real output response (negative 1 ppt money growth shock)



Notes: Left hand side: Solid line – empirical output IRF. Solid line with + markers – model output IRF. Gray areas – empirical 1 standard deviation and 90% confidence bands. Right hand side: Black solid line with markers – impulse response with nominal rigidities and credit frictions. Gray solid line with markers – impulse response without credit frictions.

To sum up, our transmission channel analysis suggests that the greater part of the real output response can be attributed to the workings of two monetary transmission channels – nominal rigidities and credit frictions. Initially both channels are of equal strength, but the credit channel's more persistent force begins to dominate the real output response after three years.[35]

4. Non-monetary losses and other transmission channels

We now turn to the discussion of those monetary transmission channels that the data indicate were of too little importance to warrant their inclusion in the structural analysis. We also document the non-monetary wealth losses associated with maritime disasters – a correlated wealth shock that could interfere with our identification strategy.

Non-monetary losses

The maritime disasters that resulted in money losses also entailed the loss of non-monetary wealth, such as ships. In this section we document that non-monetary losses were small compared to the monetary ones. Table 4 provides estimates of the value of the non-monetary wealth loss associated with maritime disasters. In each of the 31 maritime disaster years between 1 and 30 ships were lost. The resale value for ships lay in the 1600

[35] Appendix D.3 provides a further decomposition that separates the money shock's negative effect on the economy's wealth stock from its liquidity reducing effect. Nearly all of money's real effect is due to the latter, whereas the initial merchant net worth loss matters little.

to 8000 peso range (Carrasco González, 1996, p.156).[36] Using the lower value, this implies that even in the maritime disaster with the largest number of ships lost, the overall ship wealth loss amounted to no more than 0.9% of the precious metal loss. For the high re-sale value of 8000 pesos, the corresponding fraction is 4.5%. The 4.5% value, however, corresponds to an outlier event in which 30 ships were lost, whereas the median ship value loss in our sample amounts to 0.8% of the precious metal loss – even for the high-ship value scenario.[37] The amount of lives lost as a fraction of the Spanish working population was small, never amounting to more than 0.3%, even when large numbers of ships sank, and even when assuming very large crews. For more moderate crew size estimates and median ship loss numbers this fraction is negligibly small (see Table 4 for data sources).

Table 4: Value of non-precious metal losses

Precious metal share (% of import value)	Ship loss (per disaster)	Ship value		Life loss	
		Low	High	Low	High
Until late C18th:	1 to 30	*Pesos per ship:*		*Crew per 100t ship:*	
80%	(median=3)	1600	8000	30	100
From late C18th:		*Percent of metal loss:*		*Percent of labor:*	
> 55%		<0.9%	<4.5%	<0.09%	<0.3%

Sources: Precious metal import share from Fisher (1985), García-Baquero González (2003), and Cuenca-Esteban (2008). Ship values from Carrasco González (1996, p.156). The ship values are resale values that reflect ship depreciation. *Crew per ship*: Crew per 100 tonnes from de Vries (2003), quinquennial data on average ship tonnage from Phillips (1990). *Percent of labor*: Population data from Álvarez-Nogal and Prados de la Escosura (2013). Working-age (16-50) fraction (49.6%) from 1787 census described in Martín (2005).

Finally, precious metals comprised 80% of the total value of imports up to the late 18th century (García-Baquero González, 2003; Fisher, 2003). Only in the late 18th century did the share of non-metal colonial goods – such as tobacco, cacao, and sugar – increase. Fisher (2003) documents that between 1782 and 1796 43.6% of the value of the commodities imported into Barcelona and Càdiz pertained to non-metal colonial goods. To address the concern that at the end of our sample the monetary shock measure becomes diluted with a non-monetary wealth shock, we conduct a subsample analysis in which we end our sample in 1780. The results are very similar (Figure B.3 in the Appendix).

[36] Few ships made more than four transatlantic return voyages. After that, they often were sold and used in calmer waters (Carrasco González, 1996, p.156). After a long-distance voyage, early modern ships were worn out. Reparations and outfitting cost nearly as much as buying a new ship (Gelderblom et al., 2013).

[37] The majority of vessels in the Atlantic had less than 400 tonnes capacity (Carrasco González, 1996, p.157). However, ships carrying the treasure often were from the military squadron that protected the fleets – two to six military ships with a larger tonnage. Such large ships were more expensive to build. Phillips (2007) documents the construction costs for two such 1000 tonne ships in the late 17th century. Building them anew cost 63,419 pesos. Assuming a resale value of 20,000 for such ships, and assuming all sinking ships are of this type, the median value of ship losses across disaster events would add up to 1.9% of the value of the precious metal loss.

Changes in the silver value of the unit of account

In early modern Spain nominal adjustments could take place not only through a fall in wages and prices, but also through a change in the silver value of the unit of account (UOA) (Sargent and Velde, 2002; Velde, 2009; Karaman et al., 2018). Wages and prices were typically expressed in Maravedí – the Spanish UOA – and Spanish coins possessed a Maravedí face value. The most direct way in which the silver value of one Maravedí could change was through the monetary authority's decision to change the silver content of Spanish coins. This, however, rarely occurred. More important were fluctuations in the exchange rate between silver coins and copper (vellón) coins, which led to fluctuations in silver prices while the same prices expressed in Vellón Maravedí stayed constant. Here, we analyze whether changes in the silver value of the Spanish UOA contributed to the nominal adjustment of the Spanish economy in the aftermath of maritime disasters.

The silver value of the Spanish UOA was stable for most of the 16th and 18th centuries, but in the 17th century it declined and at times behaved erratically (see Hamilton, 1934, ch. 4 for a detailed description of this period). To see whether such fluctuations in the silver value of the UOA contributed to nominal adjustments in the Spanish economy we use the series by Karaman et al. (2018) to translate consumer prices and wages from silver units into Vellón Maravedí. We then re-estimate the IRFs for prices and wages (in UOA) and compare them with the original IRFs for prices and wages (in silver). Table 5 shows the results.

We find that in the short run the silver value of the unit of account was stable. Thus, whether wages and consumer prices are expressed in silver or in UOA matters little for the short-run IRFs of prices and wages. Only after 7 years does a noticeable gap open up between the silver and UOA responses. Whereas silver prices and wages permanently adjust to the lower silver stock, their UOA counterparts recover as the silver value of the unit of account decreases. In sum, while UOA devaluations seem to have facilitated nominal adjustments over longer time horizons, they were ineffective over the short horizon we analyze here.

Table 5: Reaction of nominal variables: Silver units vs. units of account (negative 1 ppt money growth shock)

Variable \ Horizon	0	1	2	3	4	5	6	7	8	9	10
					(a) Consumer prices						
In silver	0.58†	0.02	-0.11	-0.62†	-1.36**	-1.18†	-1.51*	-1.21*	-0.89†	-1.07†	-1.41**
	(0.44)	(0.48)	(0.56)	(0.50)	(0.56)	(0.82)	(0.82)	(0.71)	(0.73)	(0.65)	(0.64)
In units of account	0.50	-0.14	-0.29	-0.75†	-1.57*	-1.37†	-1.59†	-0.72	-0.58	-0.48	-0.08
	(0.67)	(0.80)	(0.75)	(0.71)	(0.85)	(0.99)	(1.17)	(1.21)	(1.40)	(1.29)	(1.46)
Difference	*0.08*	*0.16*	*0.18*	*0.13*	*0.21*	*0.19*	*0.08*	*-0.49*	*-0.31*	*-0.59*	*-1.33*
p-value	*[0.75]*	*[0.68]*	*[0.68]*	*[0.74]*	*[0.63]*	*[0.73]*	*[0.89]*	*[0.48]*	*[0.69]*	*[0.45]*	*[0.19]*
					(b) Nominal wages						
In silver	-0.48**	-0.56*	-0.53†	-0.75**	-0.47†	-0.44†	-0.78**	-0.75*	-1.28**	-1.07**	-1.31**
	(0.24)	(0.30)	(0.34)	(0.29)	(0.32)	(0.40)	(0.34)	(0.41)	(0.40)	(0.46)	(0.51)
In units of account	-0.43†	-0.59†	-0.75†	-1.04†	-0.69	-0.52	-0.88†	-0.43	-1.11	-0.61	-0.20
	(0.32)	(0.54)	(0.72)	(0.65)	(0.73)	(0.90)	(0.84)	(1.02)	(1.12)	(1.24)	(1.57)
Difference	*-0.05*	*0.04*	*0.22*	*0.29*	*0.22*	*0.08*	*0.09*	*-0.33*	*-0.17*	*-0.45*	*-1.11*
p-value	*[0.74]*	*[0.90]*	*[0.60]*	*[0.49]*	*[0.63]*	*[0.88]*	*[0.86]*	*[0.62]*	*[0.82]*	*[0.57]*	*[0.26]*
					(c) Silver per unit of account						
Silver/unit of account	0.04	-0.11	0.09	0.11	-0.07	-0.26	-0.63	-1.07†	-1.13†	-1.36†	-1.94†
	(0.23)	(0.43)	(0.57)	(0.58)	(0.66)	(0.72)	(0.87)	(0.97)	(1.09)	(1.09)	(1.23)

Notes: † 1 S.D., * 90%, ** 95%. Standard errors in parentheses. The p-value pertains to a two-sided Wald test for equality of the horizon h responses.

The Crown's finances and sovereign debt crises

Although 85 to 95% of precious metal inflows from the colonies were privately owned (García-Baquero González, 2003; Costa et al., forthcoming), the remainder nevertheless could constitute an important source of revenue for the Crown.[38] In the first half of the 16th century only 4 to 10% of crown revenues derived from American precious metals. Under Phillip II this figure rose up to 20%. In the 17th century, the share of American precious metals in crown revenues wanes again to around 11% (Ulloa, 1977; Drelichman and Voth, 2010; Comín and Yun-Casalilla, 2012; Álvarez-Nogal and Chamley, 2014). Thus, the loss of silver in maritime disasters could put stress on the Crown's finances, making a sovereign debt crisis more likely.

The Royal Treasury's revenues and expenditures were small compared to the Spanish economy – on average 3% between 1555 and 1596, and around 5% at the end of our sample (Ulloa, 1977; Drelichman and Voth, 2010; Barbier and Klein, 1981). Furthermore, a substantial share of this was not spent in Spain, but for military purposes abroad. Together with the fact that the Crown's silver revenues amounted to less than one fifth of all government revenues, this suggests that maritime disasters could only have had a small effect on Spanish government spending. Adjusting our structural analysis for the Crown's revenues and expenditures confirms this (Appendix D.1).

Table 6: Sovereign debt crises and maritime disasters

Sovereign debt crisis year	1557	1575	1596	1607	1627	1647	1686	1700
Nearest preceding maritime disaster year	1554	1567	1591	1605	1624	1641	1656	1656
Distance (in years)	3⋆	8	5⋆	2⋆	3⋆	6	30	44

Notes: ⋆ indicates sovereign debt crises that occurred within five years after a maritime disaster. Sovereign debt crisis years from Pike (1966), Homer and Sylla (1991), Reinhart and Rogoff (2009), and Álvarez-Nogal and Chamley (2014).

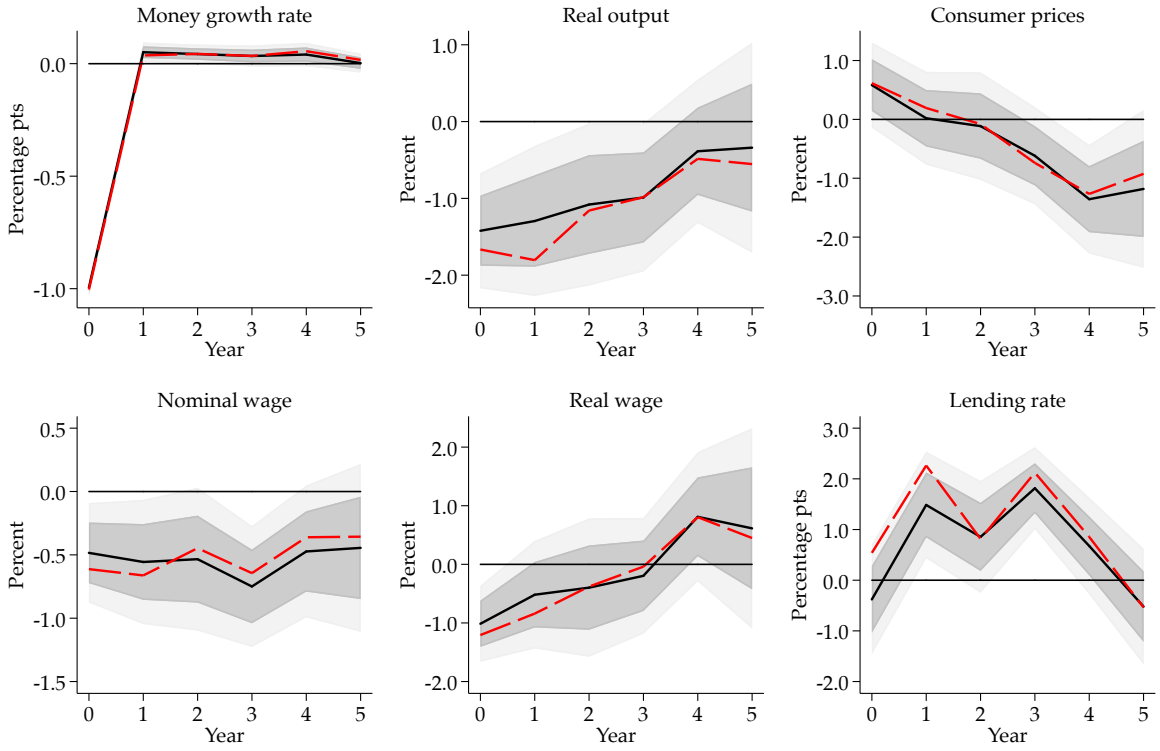
Despite the small public sector share, the public debt-to-GDP ratio was large – at times exceeding 50% according to some estimates (Álvarez-Nogal and Chamley, 2014).[39] Sovereign debt crises therefore might have negatively affected the Spanish economy through a reduction in public debt holder wealth. It is important to note, however, that during sovereign debt crises not all debt was written down. In fact, actual debt write-downs may have been quite small (Álvarez-Nogal and Chamley, 2014).

We analyze whether the real effects of money losses were the consequence of a monetary transmission through the Crown's finances in two steps. First, to see whether maritime

[38] Only in the late 18th century does the Royal Treasuries' share of precious metal remittances increase to above 20%. Note that occasionally, the Crown sequestered part of the privately owned treasure through forced loans that were reimbursed later with additional interest (Sardone, 2019).

[39] Accordingly, debt servicing costs used up a large part of government revenues.

Figure 6: Sovereign debt crises: responses to negative 1 ppt money growth shock



Notes: Solid black line – baseline specification. Dashed red line – specification controlling for separate effect of sovereign debt crises. Gray areas – 1 standard deviation and 90% confidence bands.

disasters provoked sovereign debt crises Table 6 lists the dates of sovereign defaults, together with the closest preceding maritime disaster date. Indeed, four out of the eight sovereign debt crises in our sample occurred within five years after a maritime disaster. However, this also implies that 27 maritime disasters were not followed by a sovereign debt crisis.

Second, to see to which extent our short-run monetary non-neutrality results are driven by these four sovereign debt crises we re-estimate our baseline IRFs using an adjusted specification, which allows money losses to develop different effects on the economy if they are followed by a sovereign debt crisis. In particular we amend the baseline specification from section 2.4 in the following way:

$$(Y_{t+h} - Y_{t-1})/Y_{t-1} = \alpha_h + \beta_h S_t + \delta_h S_t * C_t + \eta_h C_t + \gamma_h X_t + u_{t+h},$$

where C_t is a binary indicator that equals 0 except in sovereign debt crisis years and the five years preceding them. This purges sovereign debt crisis effects over the full five year horizon over which the IRF extends. X_t now also contains lags of the newly added interaction term and crisis dummy.

Figure 6 shows that the adjusted IRFs closely resemble the baseline IRFs, indicating that the real effects of money supply shocks did not significantly differ according to whether or not they were associated with sovereign debt crises. Thus, the Crown's finances do not appear to have played a major role in the transmission of money supply shocks.

5. Conclusion

Disentangling how money affects the economy requires counterfactual knowledge about the path the economy would have followed in the absence of the monetary authority's and financial sector's response. In this paper we use a series of natural experiments to identify the causal effects that run from the monetary side of the economy to the real side. Maritime disasters in the Spanish Empire repeatedly gave rise to large losses of monetary metals. The causes of these disasters had nothing to do with the economy in Spain, and the corresponding precious metal losses therefore resulted in exogenous variation in the Spanish money stock.

We thus contribute to a long-standing debate in economics. In 16th century Spain, theologians expressed the idea that an increase in money is absorbed by an equivalent increase in prices (de Azpilcueta, 1556; de Molina, 1597). This reasoning about the *neutrality of money* was caused by the large influx of silver coins from America that had inflated Spanish prices. Only a few decades later, against the backdrop of a coin shortage, English mercantilists hypothesized about the *non-neutrality of money*. They argued that an increase in money not only increases prices, but stimulates real economic activity (Misselden, 1622; de Malynes, 1623).

Our findings suggest that a negative 1 percentage point shock to the money growth rate led to a 1.3% decrease in real output that persisted for several years. A transmission channel analysis highlights the slow adjustment of nominal variables and a temporary tightening of credit markets as important mechanisms through which the monetary shock was transmitted to the real economy. Prices only fell with a lag, and lending rates temporarily increased by around 1.5 percentage points. We find little evidence for activity along other channels of monetary transmission. An estimated DSGE model of the early modern Spanish economy confirms that nominal rigidities and credit frictions can explain most of the non-neutrality result. Each channel explains about half of the on-impact response of real output. Much of the response's persistence can be accounted for by the credit channel.

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Appendix

to *"The real effects of money supply shocks: Evidence from maritime disasters in the Spanish Empire"*

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A. Data

A.1. Precious metal losses

Table A.1: Maritime disasters

Year	Source	Silver equivalent	Notes
1537	Walton (1994, p.24)[1], Morineau (1985, p.242)	18,258 kg	around 500,000 pesos captured
1550	Potter (1972, pp.215,299), Morineau (1985, p.242)	8,079 kg	more than 300,000 pesos sunken
1554	Walton (1994, p.61), Morineau (1985, p.242)	73,031 kg	almost 3 million pesos in treasure sunken, about half salvaged
1555	Potter (1972, pp.160,340), Morineau (1985, p.242)	21,727 kg	850,000 pesos sunken, partly salvaged
1567	Walton (1994, p.61), Morineau (1985, p.242)	109,547 kg	more than 4 million pesos sunken; salvaging failed
1591	Walton (1994, p.83)	255,610 kg	10 million pesos sunken; about 3/4 salvaged
1605	Walton (1994, pp.83-84)	204,488 kg	8 million pesos sunken; salvaging failed
1621	Marx (1987, p.302.), Mangas (1989, p.316)	382 kg	around 15,000 pesos in treasure sunken; most of it salvaged
1622	Potter (1972, pp.215ff.), Marx (1987, pp.200ff.), Mangas (1989, p.316)	188,951 kg	more than 7 million pesos in treasure sunken; partly salvaged
1623	Marx (1987, p.202), Mangas (1989, p.316)	76,345 kg	about 3 million pesos sunken
1624	Mangas (1989, p.318)	51,122 kg	2 million pesos sunken
1628	Potter (1972, p.160), Marx (1987, p.248), Mangas (1989, p.316)	30,538 kg	around 1.2 million pesos sunken, largely salvaged
1628	Venema (2010, p.213)	80,660 kg	177,000 pounds of silver and 66 pounds of gold captured
1631	Marx (1987, p.424), Morineau (1985, p.242)	58,169 kg	more than 2 million pesos sunken; 1 million pesos salvaged
1631	Marx (1987, p.249), Morineau (1985, p.242)	150,241 kg	more than 5.5 million pesos sunken; very little salvaged
1634	Sandz and Marx (2001, p.129), Mangas (1989, p.316)	7,635 kg	around 300,000 pesos in treasure sunken, partly salvaged
1641	Mangas (1989, p.318)	76,683 kg	3 million pesos sunken
1654	Earle (2007, p.83)	255,610 kg	10 million pesos sunken; 3.5 million pesos recovered

1656	Potter (1972, p.432)	173,815 kg	2 million pesos captured; around 5 million pesos sunken
1656	Walton (1994, pp.128, 140)	127,805 kg	5 million pesos sunken, 2.5 million pesos salvaged
1702	Kamen (1966)	7,350 kg	around 80,000 pesos captured by British; Dutch capture and sunken metals assumed proportional to ship capture and destruction
1708	Phillips (2007, pp.46,181), Sedgwick (1970)[2]	286,283 kg	11 million pesos sunken and 200,000 pesos captured
1711	Potter (1972, p.152), Marx (1987, p.353), Morineau (1985, p.375)	81,585 kg	more than 3 million pesos sunken; around 1.5 million pesos salvaged
1715	Marx (1987, p.431), Morineau (1985, p.375)	308,382 kg	12 million pesos sunken; around 5 million salvaged
1730	Walton (1994, p.166), Morineau (1985, p.375)	138,841 kg	more than 5.5 million pesos sunken; partly salvaged
1733	Fine (2006, p.153)	311,908 kg	around 12.5 million pesos sunken; almost all salvaged
1750	Putley (2000), Amrhein (2007, ch.1)[3]	10,321 kg	272,000 pesos sunken; 14,467 pesos salvaged; 144,000 pesos captured
1752	Marx (1987, p.443)	49,620 kg	2 million pesos sunken, mostly salvaged
1753	Marx (1987, p.443), Morineau (1985, p.375)	37,938 kg	1.5 million pesos sunken
1762	Walton (1994, p.174)	99,240 kg	4 million pesos captured
1786	Potter (1972, pp.349ff.)	185,716 kg	7.5 million pesos sunken, mostly salvaged
1800	Marx (1987, p.440), Morineau (1985, p.375)	95,700 kg	Around 4 million pesos sunken; partly salvaged
1802	Sandz and Marx (2001, p.218), Morineau (1985, p.375)	13,671 kg	Around 0.5 million pesos sunken
1804	Cobbett (1804, p.663)	112,896 kg	1.5 million pesos sunken; 3 million pesos captured

Notes: [1]loss calculated as American production destined for Spain from TePaske (2010), minus 10% American retention rate, minus the Spanish arrival figure provided in the source. [2]URL: `http://www.historyofparliamentonline.org/volume/1715-1754/member/wager-sir-charles-1666-1743#footnoteref3_g4iwhgx`. [3]Loss associated with the ship "El Salvador" corrected to 240,000 pesos; correction confirmed with the author. The following unregistered precious metal shares have been applied: 30% for the 16th century (average from Morineau, 1985, p.242), 17th century rates from Mangas (1989, p.316) or Morineau (1985, p.242), 18th century rate of 46% from Morineau (1985, p.375).

A.2. Monetary stock estimates and monetary shock measure

Baseline money stock estimate

We calculate the baseline Spanish money stock in two steps. First, we combine an estimate of the European precious metal stock in 1492 with data on European precious metal inflows, outflows, and production to calculate the European precious metal stock. Second, we calculate the Spanish share of European precious metals after 1492 according to the sample average of Spain's share of European GDP.

The European precious metal stock in 1492 is uncertain. According to Velde and Weber (2000b) when Columbus first voyaged to America the global silver and gold stocks amounted to 3600 tonnes and 297 tonnes respectively.[5] Using the contemporary silver-gold rate of 11.1 (Spooner, 1972) we arrive at an initial global precious metal stock of 6897 metric tonnes of silver equivalents. We calculate the European share of this precious metal stock according to the European-to-World GDP ratio around 1500 (= 23%) (Bolt et al., 2018).[6] The resulting value is 1577 tonnes of silver equivalents – 823 tonnes of silver and 68 tonnes of gold. This initial stock estimate forms the lower bound of our initial stock range (Palma, 2019). Glassman and Redish (1985) cite several higher initial precious metal stock estimates for Europe. Among the highest considered plausible is the 17.1 million Paris marcs argent-le-roi estimate by Del Mar (1877). This translates into 4011 tonnes of silver equivalents, which forms the upper bound of our initial stock range.[7] The mid-point of the 1577 to 4011 ton range (2794 tonnes) serves as our baseline initial stock estimate.

To obtain European precious metal inflows, we adjust the American precious metal production data from TePaske (2010) in the following ways: First, we subtract the amount of precious metals that directly went from America to Asia (Schurz, 1939; Borah, 1954; Chuan, 1969; Bonialian, 2012). Second, we account for the amount of precious metals that stayed in the Americas (Barrett, 1990, p.245).[8] Third, we subtract our precious metal

[5] Here, "tonnes" refers to metric tonnes.

[6] The European GDP figure includes Belgium, Finland, France, Germany, Greece, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland, and England. We linearly interpolate the underlying population and real purchasing power adjusted per capita GDP series from Bolt et al. (2018). For several European countries no GDP estimates exist for the early modern time period. As a result of this, the numerator in the GDP-share term is too low. However, so is the denominator, which in addition misses several non-European countries. While it is impossible to be certain whether the resulting GDP share is too small or too large, the overall error is limited by the fact that missing countries are more likely to be small.

[7] To obtain the metric ton figure we convert Paris marcs into 244.7529 grams of silver. We adjust for the fineness of the silver argent-le-roi by multiplying by 23/24.

[8] Barrett (1990, p.245) estimates that 15% of American precious metal production was either retained in America or lost in transport. In our sample, transport losses amount to a bit less than 4% of American production. This implies a 11% retention rate for American precious metals. These magnitudes are also

loss measure from the precious metal production figures to account for maritime disaster losses.[9] Fourth, assuming that salvaged precious metals entered the European economy with a delay of one year, we add the amount of last year's salvaged precious metals to the inflow measure.[10]

We combine the thus obtained inflow measure with the European precious metal outflow data from Barrett (1990), and the European production data from Soetbeer (1879) to calculate the European precious metal stock.[11] To correct for the wear of coins we apply an annual money stock depreciation rate of 0.24%. This value lies in the center of the 0.2% to 0.28% range that numismatic research has established for the depreciation of coins through wear (Velde, 2013; Mayhew, 1974, p.3).[12] When minting coins, so-called melt losses consume part of the metal. We subtract one-time melt losses of 0.52% from the American and European precious metal production (Mayhew, 1974, p.3).

Based on the European money stock, M_t^{EU}, we calculate an intermediary measure for the Spanish money stock according to the sample average of Spain's share of European GDP, χ:

$$\widetilde{M}_t^S = M_t^{EU}\chi, \qquad \chi \equiv \frac{1}{T}\sum_t \left(\frac{GDP_t^S}{GDP_t^{EU}}\right). \tag{A.1}$$

For this purpose, we rely on real purchasing power adjusted GDP data from Bolt et al. (2018), as described in an earlier footnote. We calculate European GDP as the sum of the GDP of Belgium, Finland, France, Germany, Greece, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, Switzerland, and England. Spain's GDP share fluctuates between 13% and 16%. We choose the mean value of Spain's GDP share so that the resulting money stock estimate does not reflect fluctuations in economic activity.[13]

consistent with the 5% loss figure for transatlantic treasure flows given by Potter (1972, p.xix).

[9] Piracy losses constituted a redistribution of precious metals within Europe, and thus do not count as a transport loss on the European level.

[10] Most salvaging operations were concluded within one year. Only in a few cases, where access to the treasure was complicated, e.g. by bad weather, were salvaging operations extend beyond one year.

[11] The European precious metal production data is made up of bidecennial observations. We sum the linearly interpolated production data from all European regions to arrive at European precious metal production. Note that the production data by Soetbeer (1879) are consistent with the more recent production series provided by Munro (2003). The former, however, covers more regions and our full sample period, while the latter only covers South-German and Central European mining output from 1471 to 1550.

[12] Note that several other publications have chosen a 1% depreciation rate (Motomura, 1997; Velde and Weber, 2000b). The value of 1%, however, accounts for more varieties of precious metal loss than pure wear, such as losses in transport and loss arising from the balance of trade (Patterson, 1972; Mayhew, 1974). Here, we focus on depreciation through wear, because our measure takes trade-related precious metal outflows and transport losses directly into account.

[13] This approach assumes that in the long-run money stocks within Europe evolved according to the equation of exchange $MV = PY$. To see this, divide the equation of exchange for Spain, $M^S V^S = P^S Y^S$, by the same equation for Europe, $M^{EU} V^{EU} = P^{EU} Y^{EU}$. Assuming $V^S = V^{EU}$, and assuming purchasing power parity holds, i.e. $P^S = P^{EU}$ when both price levels are expressed in silver terms, it follows that the ratio of real GDPs equals the ratios of monetary stocks, $\frac{Y^S}{Y^{EU}} = \frac{M^S}{M^{EU}}$.

Next, we make several adjustments to the intermediary stock measure, $\widetilde{M}_t^{Spain}$, to arrive at our *baseline* measure for the Spanish money stock. First, we subtract the cumulative sum of piracy related money losses, because they constituted only Spanish losses, not European ones. Second, we correct for the rescaling of the non-piracy related disaster losses in equation A.1, recognizing that the entire loss was initially born by Spain.[14] The same logic applies to salvaged precious metals. This is achieved by subtracting the following cumulative sum from each time point t of the series: $\sum_{k=1531}^{t} \left[(loss_k - salv_{k-1}) \cdot (1 - 0.24\%)^{(t-k)}\right] \cdot (1 - \chi)$, where χ denotes the sample average of Spain's share of European GDP.

While transatlantic transportation losses were initially born by Spain and its merchants, it has to be assumed that over time this loss diffused across Europe, because other countries received fewer Spanish precious metals as a consequence of the Spanish loss. Spain also might have received more precious metals from other European nations, as its price level became more competitive in the aftermath of the loss. In this way, part of the initial loss is added back to the Spanish money stock. We assume that in the long-run Spain only bears a fraction of the loss that corresponds to its share of European GDP. Note that piracy losses constituted a redistribution of precious metals, not a permanent reduction in global precious metal stocks. Thus, we assume that in the long-run piracy losses had no effect on the Spanish money stock. To this end we add a diffusion term to the intermediary stock measure $\widetilde{M}_t^S$.[15]

Finally, we account for valuation changes in the Spanish money stock that occurred as a consequence of changes in the gold-silver exchange rate. Over our sample period the price of gold in terms of silver increased. This implies that the stock of gold coins expressed in silver equivalents increased over time due to a valuation effect. To take this into account we first calculate the Spanish gold and silver stocks separately, and then add them up, using the gold-silver exchange rate (Spooner, 1972; Soetbeer, 1879) to translate gold quantities into silver equivalents.[16] The resulting *baseline* stock measure is depicted

[14] By regulation, only Spanish merchants were allowed to engage in transatlantic business with the Spanish colonies (Nogues-Marco, 2011a, p.6). Thus, although much of the precious metals arriving in Spain eventually diffused through Europe, they first passed through some Spanish entity that was the initial owner of the precious metals.

[15] The diffusion takes place after 5 years, over a 10-year period. This temporal pattern roughly corresponds to a recovery of prices and wages after a loss. As a robustness check we also consider scenarios in which 50% of the Spanish silver inflows leave Spain within the same year – i.e. diffusion is instantaneous. While Spanish merchants, as the owners of the silver, still bear a net wealth loss amounting to 1% of the money stock, the Spanish money stock only falls by 0.5%, as silver outflows decrease on impact. In this scenario the deflationary pressure on the Spanish economy is smaller, and the nominal rigidities' contribution to the real output drop halves. However, nominal rigidities and credit frictions together still explain the majority of the real output response.

[16] While the gold and silver production data allow us to calculate separate gold- and silver inflow measures, we have to make assumptions about how outflows, transport losses, and diffusion flows were allocated across the gold and silver stocks. We assume this allocation corresponded to the American

as the solid black line in Figure A.1a.

Alternative money stocks

In this section we assess the robustness of our findings with respect to the Spanish money stock measure. We do so by calculating two alternative money stock measures for Spain. The first alternative stock measure combines Spanish precious metal inflows with the available information about Spanish precious metal outflows to obtain a money stock estimate. The second stock measure simplifies the calculation of the European precious metal stock by replacing the European precious metal outflow data and the Pacific precious metal flow data with one number that describes the fraction of American-produced precious metals that eventually wound up in Asia. The simplicity of this approach lends itself to the calculation of a plausibility range for the European money stock.

The *baseline* measure assumes that European precious metal inflows and outflows are representative of Spanish in- and outflows. However, European precious metal outflows may underestimate Spanish outflows for the 18th century, when Spanish precious metals quickly hemorrhaged into the rest of Europe. We therefore calculate an *outflow-based* money stock measure based on the sparse data on Spanish precious metal outflows that is available for our sample period (Attman, 1986; Walton, 1994). The Spanish outflow data shows that the fraction of American Spanish precious metal inflows that left Spain increased from 85-90% in the 17th century to 100% in the 18th century. In late 18th century, inflows again start to exceed outflows. More generally, during severe military conflicts outflows often exceeded inflows from America, whereas in normal times Spain retained between 10 and 15% of these inflows. We are unaware of any source for Spanish precious metal outflows prior to the late 16th century. At the beginning of our sample, we therefore assume a retention rate of 87.5%, which is representative of Spanish retention rates in the 17th and late 18th centuries outside of periods of severe conflict. We use the linearly interpolated Spanish outflow-to-inflow ratio, o_t, to calculate the money stock.

Spanish precious metal inflows in this calculation consist of the flows arriving from the Spanish colonies in America, I_t.[17] This equals the European inflow measure described earlier, minus the notable production of precious metals in Portugal's American possessions, I_t^{PRT}. We also add part of the European precious metal production, P_t^{EU}, to the Spanish stock measure. In particular, we add a fraction corresponding to the sample average of Spain's real GDP share in Europe.[18] First, however, we subtract that part of the

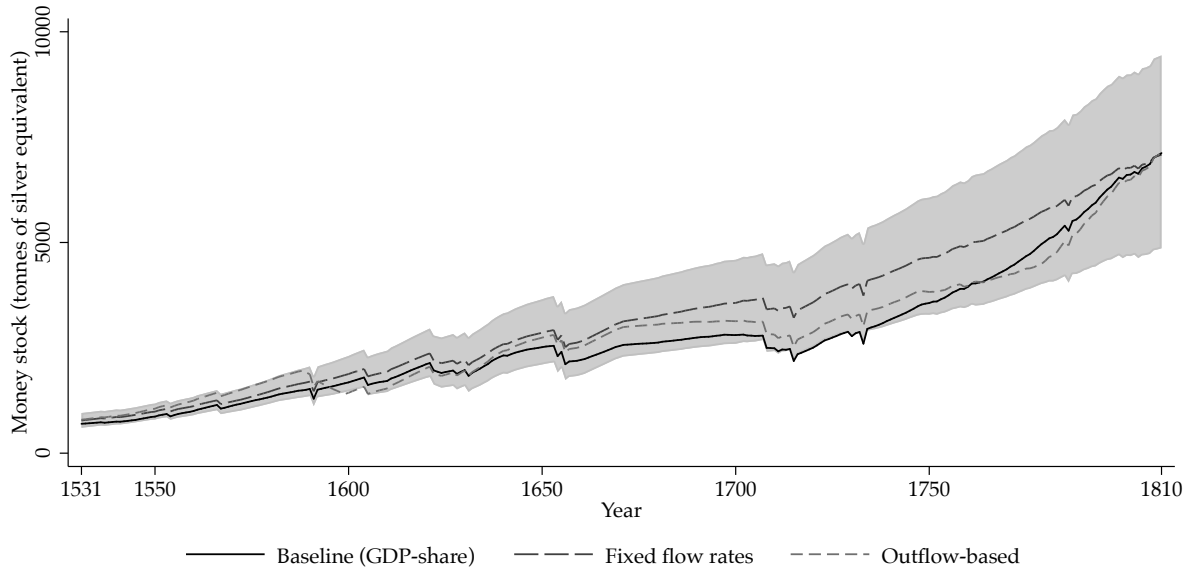
production shares. This ensures that the gold-silver composition of the Spanish money stock stays in line with the supply data. For the initial gold-silver shares we use the 1492 data by Velde and Weber (2000b) described earlier.

[17] The inflows account for transportation losses, which in the case of Spain include losses due to piracy.

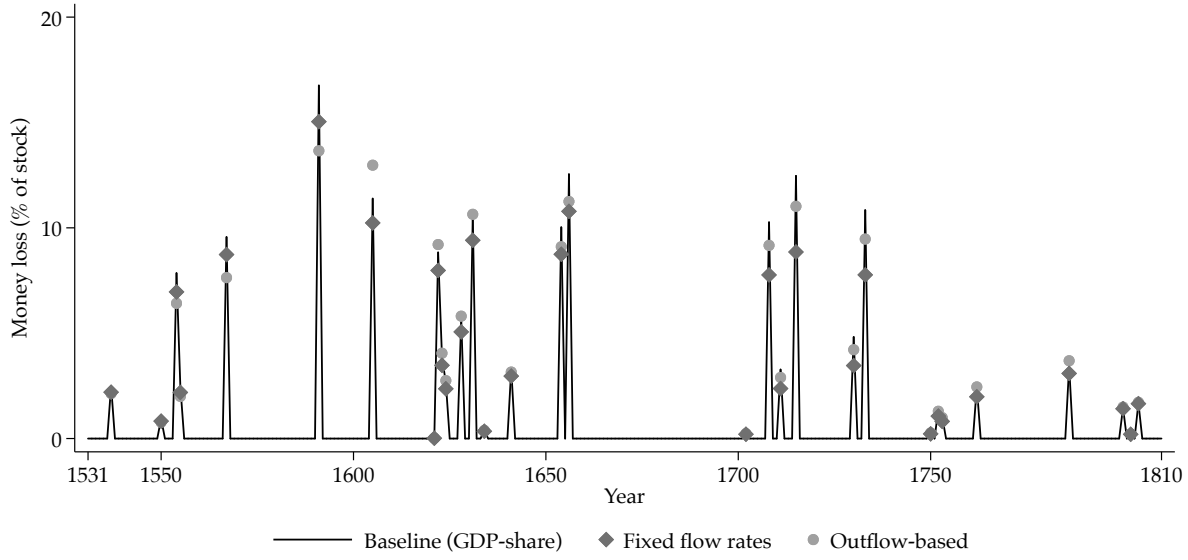
[18] Precious metal mining in Spain itself almost completely stalled after the discovery of the American

Figure A.1: Alternative money stocks and shock sizes

(a) Alternative money stocks



(b) Alternative shock measures



Notes: The gray range depicts the Spanish money stock range corresponding to the 33% to 66% range for Asian precious metal retention (see text).

European production quantity that flows from Europe to the rest of the world. Absent more concrete information we assume that this fraction equals the ratio of European outflows to the European precious metal stock, $out_t^{EU}/M_t^{EU} \approx 0.75\%$. We treat Portuguese precious metal inflows from America analogously to European precious metal production. Thus part of it is added to the Spanish money stock. Finally, we add a diffusion term, d_t,

mines and only resumed again in the 1820s (Soetbeer, 1879).

that ensures that the Spanish money stock level in the long-run only falls by the initial loss times the sample average of Spain's world GDP share.[19] As in the baseline stock measure, this takes into account that, although maritime disaster losses in the Spanish Empire initially hit the Spanish money stock, purchasing power parity and the equation of exchange, $MV = PY$, suggest that losses ultimately diffused globally according to real GDP shares. All in all, we calculate the *outflow-based* money stock measure as

$$M_t^{S,\text{out}} = M_{t-1}^{S,\text{out}}(1-0.24\%)+I_t(1-0.52\%)(1-o_t)+\chi(1-\frac{out_t^{EU}}{M_t^{EU}})(P_t^{EU}+I_t^{PRT})(1-0.52\%)+d_t. \tag{A.2}$$

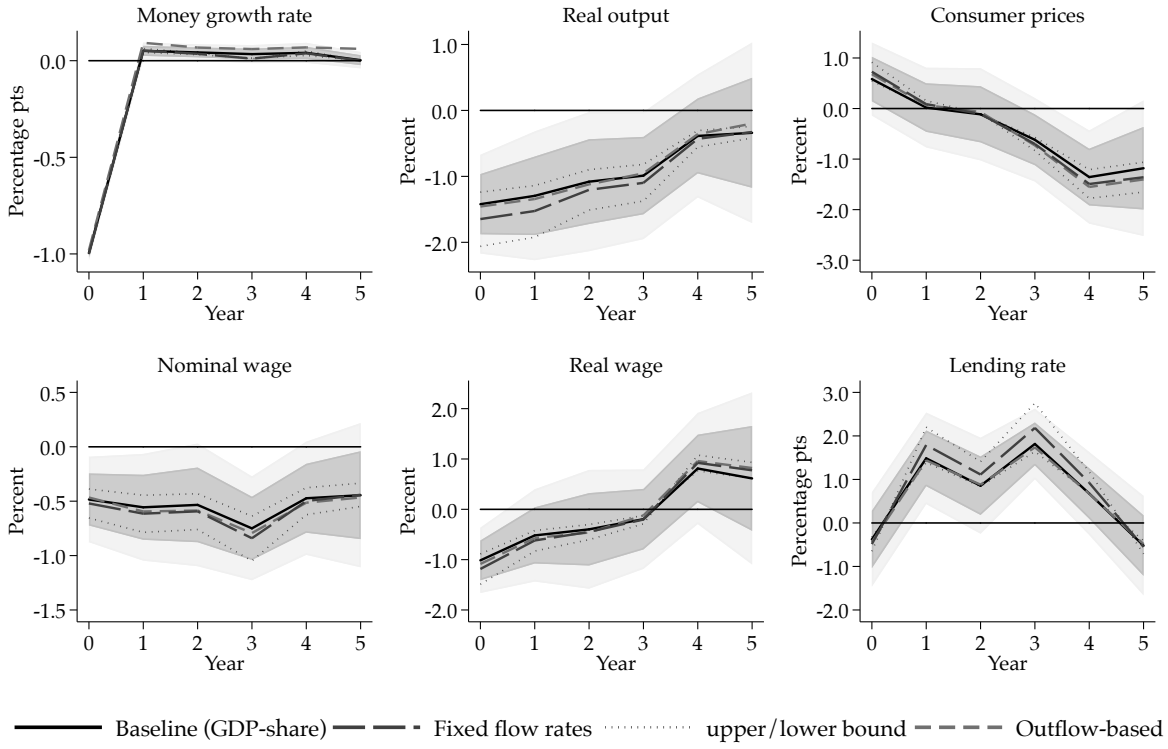
The initial value for the Spanish money stock is set to the same value as before, and the same depreciation rate of 0.24% and melt loss of 0.52% are applied. In Figure A.1a the *outflow-based* series is depicted as the long-dashed, gray line.

The second alternative stock measure is calculated along the same lines as the baseline measure – as a share of the European stock. In the calculation of the European stock, however, the Pacific flows and European outflows are replaced with existing estimates of the fraction of the American precious metal production that found its way to Asia – regardless of whether it went directly from America over the Pacific or whether it first arrived in Europe and then continued flowing east. According to some accounts the majority of American precious metals eventually wound up in East Asia, whereas others put Asian precious metal absorption only at one third to 40% (Irigoin, 2009, and references therein). To reflect this uncertainty we calculate a range of European stock estimates assuming the Asian absorption rate was at least 33%, but no more than 66%. The gray range in Figure A.1a shows the resulting Spanish money stock. The dashed line indicates the center of this range, which is based on a 50% Asian absorption rate. Starting in the mid-17th century this series lies somewhat above the baseline stock measure, but the gap closes again towards the end of our sample. Reassuringly, the outflow-based measure, as well as the baseline measure for the most part lie within the 33% to 66% money stock range described by the gray area.

The different money stock measures give rise to different monetary shock series (Figure A.1b). The *baseline*, *outflow-based*, and *fixed flow rate* shock measures are very similar up to the mid 17th century, after which the *outflow-based* shocks grow larger. Figure A.2 reveals to which extent the different shock measures give rise to different IRFs for our outcome variables of interest. The figure shows that the sizes and shapes of the IRFs are robust to plausible alterations the money stock estimate.

[19] Analogously to the baseline stock measure, the non-Spanish loss share is added back to the Spanish stock in line with the empirically observed recovery of prices – after 5 years, over a 10-year period.

Figure A.2: Impulse responses to negative 1 ppt money growth shock (different stocks)



Notes: Gray areas – 1 standard deviation and 90% confidence bands.

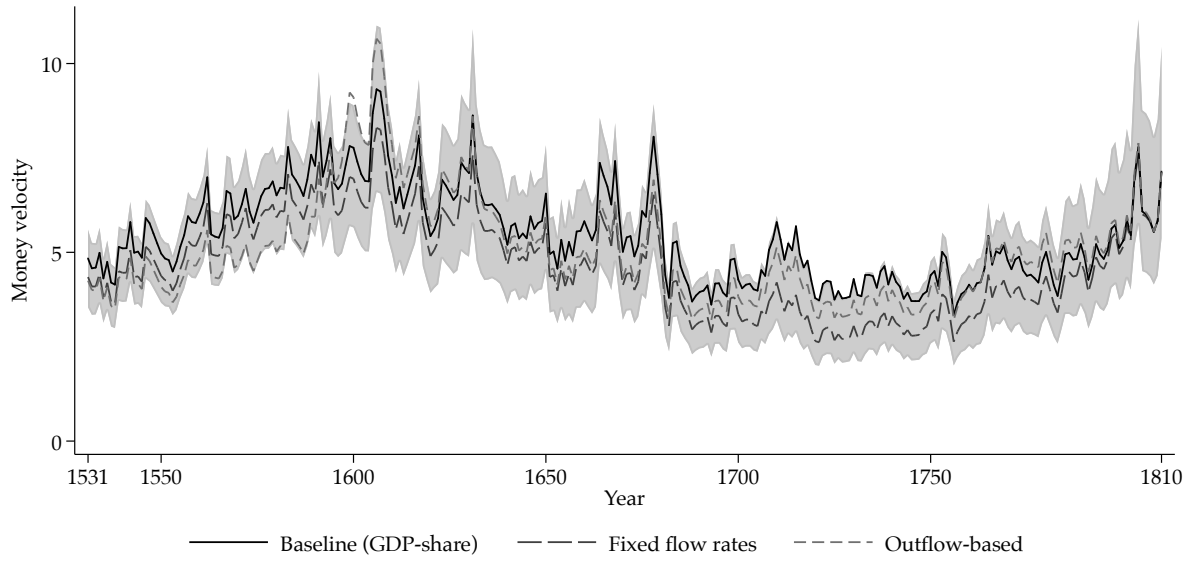
Validity checks

A look at money velocities can act as a validity check for the money stock series. We divide Spanish nominal GDP (in pesos) by our estimates of the Spanish money stock (translated into pesos). Figure A.3 shows that the money velocities for the *baseline*, *fixed flow rate*, and *outflow-based* estimates range from 4 to 9. This is in line with velocity estimates for other European economies during our sample period (Palma, 2018). The velocities exhibit no trend over our sample period. This is consistent with the absence of major regime changes in the monetary system at the time. Money was primarily gold and silver based at the beginning of the sample, as well as at its end. Only in the 19th century did other forms of money, such as bank notes, become important.

We now compare our stock estimates to the available mint output data. First, we use the Spanish minting data provided by Motomura (1997)[20] to calculate the Spanish money stock in 1634 as the 30-year cumulated Spanish mint output between 1604 and 1634. This 30-year rule of thumb was first employed by Spooner, and later by Challis (1978). It should be noted that this approach results in only the most approximate guess (see

[20] We linearly interpolate several missing data points.

Figure A.3: Money velocities



Notes: The gray range depicts the Spanish money stock range corresponding to the 33% to 66% range for Asian precious metal retention (see text).

Mayhew, 1995, 2013; Lucassen, 2014, for more recent applications). Using the 30-year rule we arrive at a Spanish stock estimate of 4124 tonnes for 1634. This is about two times the amount of our stock estimate. Which stock level should be preferred?

According to the cumulated mint output, money velocity in 1634 equalled 3, which is very low. In general, the 30-year rule may be less suitable for estimating money stocks in early modern Spain, because large quantities of precious metals were lost through trade deficits with other European countries Velde and Weber (2000a). Together with the fact that the *baseline*, *outflow-based*, and *fixed flow rates* estimates agree on a lower level, this inclines us to regard the 1634 mint output-based stock estimate as an overestimate.

Another way to validate our money stock estimates is to compare our 1810 end-point estimate with the earliest available money stock estimates for the 19th century. Tortella et al. (2013, p.78) reports a gold and silver coin stock level estimate for 1875 that amounts to 7265 tonnes of silver equivalents. Our *baseline*, *fixed flow rate*, and *outflow-based* estimates for 1810 are 7162, 7105, and 7192 tonnes respectively. This implies very little money growth in the 65 years after 1810. This meshes nicely with global events after 1810.

While silver inflows reached record levels in 1810 (Tutino, 2018, p.244) they collapsed after that. This was due to British control over the Atlantic, the loss of Spanish control over its American colonies, and drastic declines in American silver production (Walton, 1994, p.196). In the turmoil following New Spain's (Mexico's) independence, its silver

mining output remained at around half its 1810 level until 1840 (Tutino, 2017, p.175). On top of this, American retention rates increased as American populations grew quickly in the 19th century.[21] Against this backdrop the lower bound *fixed flow rate* estimate of 4861 tonnes for 1810 should be considered too low, because it implies that the Spanish coin stock grew at about the same rate after the independence of its American colonies as before. The actual 1810 money stock value is likely to lie closer to the *baseline* estimate.[22]

[21] More generally, in the 19th century, for many countries the amount of precious metals they attracted increasingly fell short of output growth. Partly this gave rise to deflation, partly this was compensated by the 19th century growth in non-metallic forms of money, such as bank notes and bank deposits.

[22] Carreras de Odriozola and Tafunell Sambola (2006, p.678), based on unpublished work by Tortella (n.d.), present an estimate for the stock of precious metal coins in 1830 of 2214 tonnes of silver equivalents. Tortella (n.d.) in addition presents a stock estimate for 1775 which is equivalent to 563 tonnes of silver. The 1775 estimate is based on Spanish mint output during the Empire-wide recoinage of 1772 to 1778. It is important to notice that recoinage was not compulsory for private holders (Hamilton, 1947, p.66). As a consequence, not all money was re-coined. For example, in the viceroyalties of New Spain (Mexico) and New Granada (Colombia) only between 28 and 50% of the local money stock was recoined (Moreno, 2014). This explains the low stock value for 1775, which implies an implausibly high velocity of 36 according to the GDP series by Álvarez-Nogal and Prados de la Escosura (2013). The 1830 stock estimate is a mint output-based backward extension of stock estimates for the second half of the 19th century. As argued earlier, Spanish mint output is only vaguely related to the evolution of the Spanish money stock. Large quantities of money arrived from abroad in minted form and thus never passed through Spanish mints. At the same time, specie flowed from Spain to other countries. As discussed earlier, the 30-year mint output rule probably severely overestimates the Spanish money stock. Analogously, subtracting more than three decades of mint output to extend the Spanish money stock series backwards probably severely underestimates earlier stocks, as is pointed out in Tortella's unpublished work itself. This can explain the low stock value for 1830, which implies the implausibly high velocity of 20 according to the GDP series by Álvarez-Nogal and Prados de la Escosura (2013).

A.3. Lending Rates

It is possible to estimate (unobserved) lending rates from (observed) bills of exchange prices (Flandreau et al., 2009a; Nogues-Marco, 2011b). In this section we illustrate the two methods we use.

Accounting for nominal exchange rate fluctuations

Consider the following non-arbitrage condition: Suppose a London merchant possesses Pound Sterling (S), but wants to obtain 1 Spanish Peso (P) in Seville in one month's time. The merchant can do this in two ways. First, he can buy a bill of exchange on Seville with one month maturity for U_t^L Pounds in London. This bill of exchange entitles the merchant to receive 1 Spanish Peso in Seville in exactly one month. Alternatively, he can purchase Pesos on the spot exchange market in Seville at the spot exchange rate $E_t^{P/S}$ (Pesos per Pound Sterling). The merchant could then lend out the obtained Pesos in Seville for one month and earn the Seville monthly gross lending rate R_t^S. Thus, to receive 1 Peso in one months time, the second approach requires the merchant to initially buy $1/R_t^S$ Pesos for $1/[E_t^{P/S} R_t^S]$ Pounds.

This example clarifies how the price of a bill of exchange can be interpreted as containing a spot exchange rate component and a lending rate component:

$$U_t^L = 1/[E_t^{P/S} R_t^S]. \tag{A.3}$$

Taking logs and detrending we obtain

$$\hat{r}_t^S = -\hat{u}_t^L - \hat{e}_t^{P/S}, \tag{A.4}$$

where small letters denote logs, and detrended variables are denoted with hats. Bill of exchange prices inform us about $\hat{u}_t^L$. To obtain an estimate for fluctuations in the Seville loan rate, $\hat{r}_t^S$, we need information about the spot exchange rate fluctuations, $\hat{e}_t^{P/S}$.

In our sample, currencies were commodity based. Spot exchange rates thus depended on the relative price of different monetary metals – typically gold or silver. This can be seen by comparing fluctuations in silver-gold rates with fluctuations in the price of short sight bills. Short sight bills were redeemable immediately upon presentation to the payer; their price thus resembles a spot exchange rate. Figure A.4 compares fluctuations in the silver-gold rate with fluctuations in the Amsterdam price for a short sight bill on London. Although fluctuations in the silver-gold rate are not perfectly described by fluctuations in the Amsterdam price bill price, the two series are highly correlated.

Figure A.4: Exchange rate vs. gold-silver rate

Notes: Exchange rate data based on Amsterdam price of short sight bill on London. Cyclical fluctuations based on HP detrended series ($\lambda = 6.25$).

Absent short sight bill prices for Spanish cities, we therefore use silver-gold rates as an indicator for spot exchange rates to calculate Spanish lending rates according to equation A.4. For two silver-based currencies, e.g. Dutch Guilders and Spanish Pesos, this assumes that bill of exchange price fluctuations represent lending rate fluctuations. By contrast, for a gold-based currency, e.g. Pound Sterling after 1717, we subtract silver-gold rate fluctuations from bill of exchange price fluctuations to arrive at Spanish lending rates.

Cancelling nominal exchange rate fluctuations

Gold-silver rate fluctuations can be an inaccurate proxy for nominal exchange rate fluctuations. This is because transportation costs can impede the arbitrage that would align nominal exchange rates with (bi-)metallic exchange rates (Bernholz and Kugler, 2011; Nogues-Marco, 2013). This opens the door for slight deviations between nominal exchange rates and (bi-)metallic exchange rates. For example, in the aftermath of a maritime disaster an acute shortage of Spanish silver coins may lead to an appreciation of Spanish peso coins in spot exchange markets that is not reflected in the gold-silver rate.

An alternative way to derive interest rates cancels out such deviations by using the prices of bills of exchange of different maturity. Consider an Amsterdam bill of exchange on Seville with 1-month maturity and a London bill of exchange on Seville (or another

Spanish city) with 2-month maturity. The price for the Amsterdam bill is

$$U_t^{A,1m} = 1/[E_t^{P/G} R_t^{S,1m}], \tag{A.5}$$

where $E_t^{P/G}$ is the spot exchange rate between Dutch Guilders and Spanish Pesos (Pesos per Guilder), and $R_t^{S,1m}$ is the one-month lending rate in Seville. Analogously, the price for the London bill of exchange is

$$U_t^{L,2m} = 1/[E_t^{P/S} R_t^{S,2m}], \tag{A.6}$$

where $R_t^{S,2m}$ is the two-month lending rate in Seville. Dividing the two prices, we arrive at

$$\frac{U_t^{A,1m}}{U_t^{L,2m}} = \frac{E_t^{P/S}}{E_t^{G/S}} \frac{R_t^{S,2m}}{R_t^{S,1m}} = E_t^{S/G} R_t^{S,1m}. \tag{A.7}$$

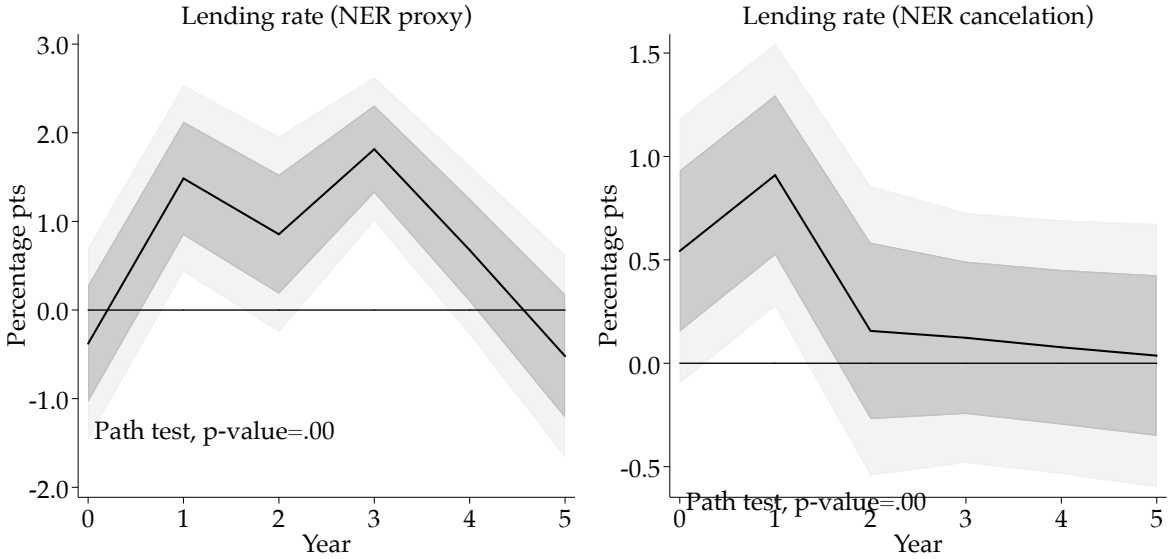
$E_t^{S/G}$ is the spot exchange rate between Pounds Sterling and Dutch Guilders (Pounds per Guilder). In other words, fluctuations of the nominal exchange rate of Spanish currency is cancelled out of expression A.7. What remains is the nominal exchange rate between two non-Spanish currencies that arguably is less likely to be affected by maritime disasters in the Spanish Empire. The log-detrended relative price of two bills of exchange of different maturity thus can serve as a proxy of the variation in the Spanish monthly interest rate. The main drawback of this alternative approach is the scarcity of suitable bill of exchange pairs of different maturity. As a consequence, this approach produces one third fewer observations than the (bi-)metallic ratio-based approach.

Figure A.5 compares the IRFs of both lending rate measures. According to both measures lending rates increased by around 1 percentage point in the short run. In contrast the the NER proxy rate, the NER cancelation rate response is short-lived, and exhibits no significant response after two years. For both IRFs the path test rejects the null of no-response at the 1% significance level.

Data on bill of exchange prices

Europe's early modern financial centers quoted bills of exchange prices for several Spanish market places. In our data collection we focus on quotations from the largest financial centers (Amsterdam, London, Paris), as well as several other important nodes in the European financial network (Antwerp, Bisenzone fairs, Genoa, Hamburg, Venice) (Flandreau et al., 2009b). Since the bill of exchange price data for specific financial hub-destination pairs are often limited in length, we combine price quotations from different financial hubs to construct long-run time series (Table A.2). Based on these, we use equation A.4 to calculate fluctuations in the average Spanish lending rate as $\hat{r}_t^{Spain} = \frac{1}{I} \sum_i \hat{r}_t^i$, where

Figure A.5: Alternative lending rate responses (negative 1 ppt money growth shock)



$i \in$ {Barcelona, Cadiz, Madrid, Medina del Campo, Saragossa, Sevilla}. Lending rate responses for all individual cities are shown in Figure B.7 in Appendix B.

The maturity of a typical bill of exchange ranges between 1 and 3 months. We use bills of M months maturity to calculate annual interest rates as follows: $\hat{r}_t^{annual} = \frac{12}{M}\hat{r}_t^{Mmonths} = -\frac{12}{M}\hat{u}_t^{Mmonths} - \frac{12}{M}\hat{e}_t^{P/S}$. We obtain detrended logarithms of the prices of bills of exchange, $\hat{u}_t^{Mmonths}$, by applying the HP filter with the smoothing parameter, λ, set to 6.25.

Note that this approach provides us with estimates of trend deviations in loan rates, not estimates of loan rate levels. This is an important difference to the approaches pioneered in Flandreau et al. (2009a) and Nogues-Marco (2011b), which result in loan rate level estimates.

For the alternative method to derive Spanish interest rates, pairs of bills of exchange with different maturities are required. When data of such pairs are not available for the same Spanish city, we use bills of exchange on different Spanish cities (Table A.3). The proxy for the Spanish interest rate is calculated with equation A.7, and then converted to a detrended logarithm series. The maturity difference between the bills of exchange is always one month. Thus the resulting interest rate is monthly. This monthly rate is then multiplied by 12 to arrive at the annual rate.

Table A.2: Bills of exchange, NER proxy

Time period	Destination city	Financial center
1590 - 1796	Amsterdam	London (1698: Antwerp)
1575 - 1685	Antwerp	Bisenzone
1686 - 1697		London, Bisenzone
1756 - 1764		London, Venice
1678 - 1689	Cadiz	Amsterdam
1690 - 1710		Amsterdam (1700: Antwerp)
1711 - 1808		Amsterdam
1598 - 1722	Barcelona	Bisenzone
1591 – 1722	Frankfurt	Bisenzone
1776 – 1785		Leghorn
1805 – 1811		Paris
1552 - 1674	Genoa	Bisenzone
1678 - 1698		Amsterdam
1699 - 1811		London
1626 - 1666	Hamburg	Venice
1667 - 1811		London
1593 - 1654	London	Amsterdam
1657 - 1686		Amsterdam, Hamburg
1687 - 1806		Hamburg
1580 - 1607	Madrid	Bisenzone
1661 - 1734		Amsterdam
1735 - 1811		London
1579 - 1722	Medina del Campo	Bisenzone
1575 - 1722	Milan	Bisenzone
1740 - 1796		Venice
1619 - 1714	Paris	Amsterdam
1715 - 1811		Hamburg
1598 - 1722	Saragossa	Bisenzone
1575 - 1681	Seville	Bisenzone
1681 - 1712		Amsterdam, Bisenzone
1713 - 1804		Amsterdam
1619 - 1696	Venice	Amsterdam, Bisenzone
1698 - 1807		London

Table A.3: Bills of exchange, NER cancelation

Time period	Destination city	Financial center	Maturity (month)
1563 - 1596	Valencia	Lyon	1
	Seville	Antwerp	2
1678 - 1699	Cadiz	Amsterdam	1
	Madrid	Amsterdam	2
1700 - 1710	Cadiz	Antwerp	1
	Cadiz	Amsterdam	2
1713 - 1789	Madrid	Amsterdam	2
1801 - 1811	London	Madrid	3

A.4. Annual real output

In our analysis we use the annual real output data that Álvarez-Nogal and Prados de la Escosura (2013) have compiled for the period from 1270 to 1850. Here we discuss several features of this data in more detail.

Primary vs. non-primary production

The real GDP series by Álvarez-Nogal and Prados de la Escosura (2013) relies on interpolated data for the urban manufacturing sector, which at the time employed between 10 and 20% of the Spanish labor force. Thus, the resulting output series is likely to be too smooth, and impulse response functions (IFRs) estimated on the basis of this series are likely to underestimate the total Spanish output response. To remedy this, we rescale the primary production series from Álvarez-Nogal and Prados de la Escosura (2013) by dividing it by the primary sector's labor share. The resulting series reflects total output fluctuations, under the assumption that urban manufacturing output experienced the same percentage fluctuations as primary sector output. Figure A.6 depicts this series, which underlies our baseline results. Most maritime disasters are either associated with an immediate decline in real output, or output declines in the subsequent year. Put differently, disaster years are located at local output troughs or are followed by output declines. Only very few maritime disasters are located on an ascending part of the real output series. This is born out in the average growth rates around disaster events depicted in panel (b) of Figure A.6.

As a robustness check, we also estimate output IRFs based on the limited amount of non-primary real output data that is available. In particular, we use wool production data from Phillips and Phillips (1997) and La Force (1965), as well as data on the number of ships built in Gipuzkoa from Oyarbide (1998). The shipbuilding data is decennial and thus does not provide an accurate description of output fluctuations in the short-run. If linearly interpolated, however, it may still convey an idea of output fluctuations at lower frequencies. We then add the non-primary output series to the primary output series by Álvarez-Nogal and Prados de la Escosura (2013) (in log-detrended form) to obtain two alternative indicators of total output fluctuations

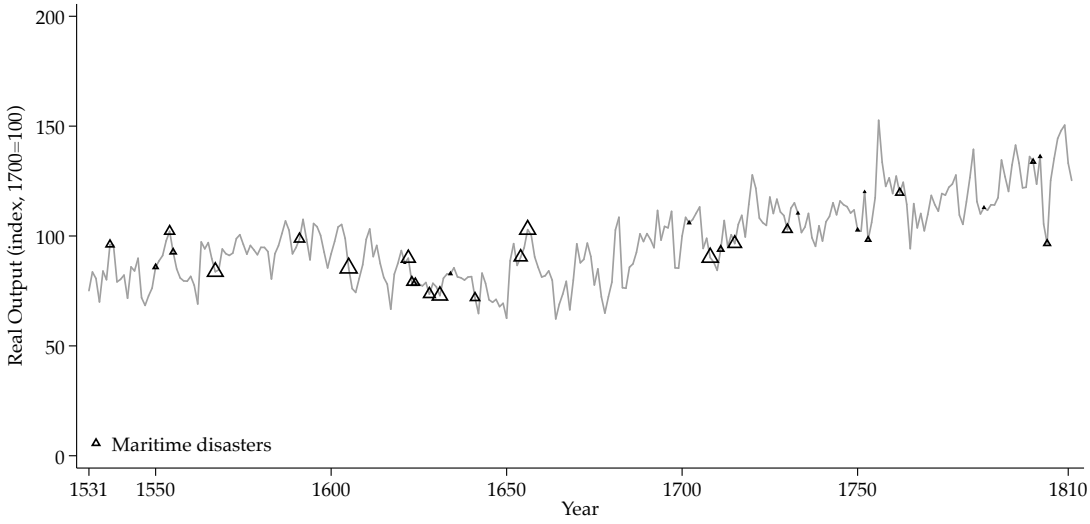
$$\tilde{y}_t = \iota \tilde{y}_t^P + (1-\iota)\tilde{y}_t^{NP}, \tag{A.8}$$

where $\tilde{y}_t$ denotes log-detrended real output, the P and NP indices denote the primary and non-primary sector components, and ι is the primary sector labor share, equalling 20%.

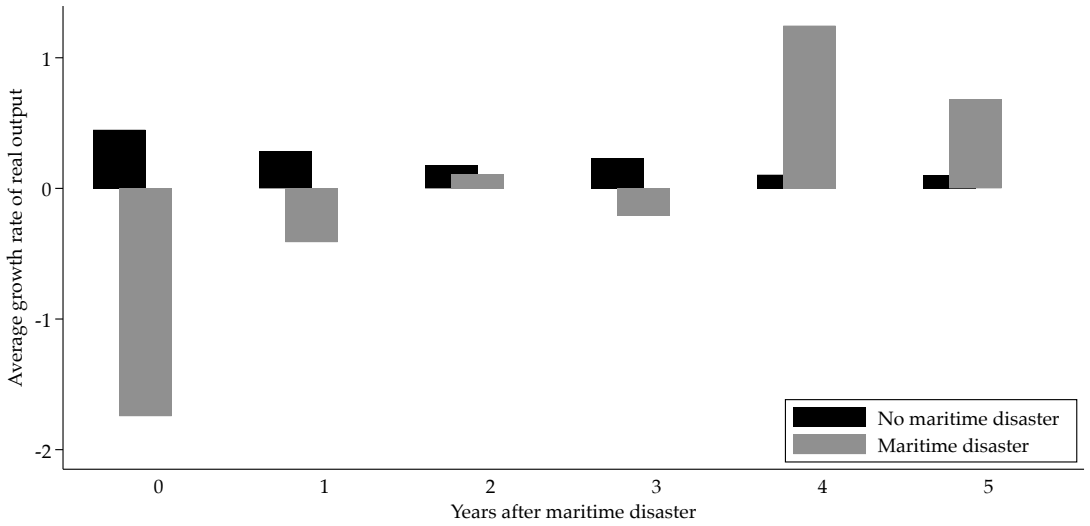
It should be noted that we lose about half of the full sample's observations due to

Figure A.6: Real output around disaster events

(a) Time series



(b) Average growth rates



Notes: Size of triangles indicates size of monetary loss associated with maritime disaster, excluding salvaged precious metals.

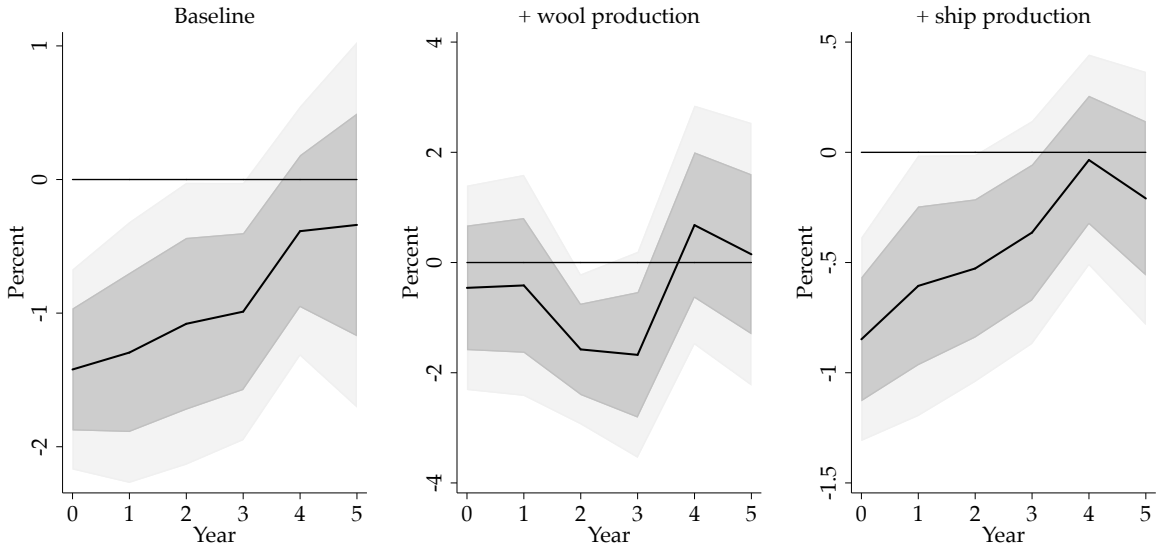
missing observations in the wool production data, and about 10% of observations for the interpolated shipbuilding data. Furthermore, the geographic coverage of the wool production data, as well as the shipbuilding data is more restricted than that of the primary sector production series by Álvarez-Nogal and Prados de la Escosura (2013). The following results are thus less representative of the Spanish economy as a whole, but they nevertheless throw some additional light on the behavior of Spanish output.

The IRFs for the two alternative output series are shown in Figure A.7, together with the baseline output response. The wool production-based series exhibits a delayed response, but then falls strongly in years 2 and 3. Note that the wool production series

on its own responds even more strongly, falling by 4 to 5% in years 2 and 3. The wool production data thus confirm that negative money shocks developed real effects in the Spanish economy.

The shipbuilding-based IRF is of similar shape than the baseline IRF, but somewhat weaker. This reflects the absence of a significant response in the shipbuilding data. This IRF thus may be interpreted as a lower bound estimate for how Spanish output reacted, assuming that only primary output responded to negative money shocks, while non-primary output did not. The shipbuilding industry may also be special in that the loss of ships in maritime disasters may have temporarily increased the demand for new ships to replace the lost ones.

Figure A.7: Alternative output indicators: Wool production and shipbuilding



Real output and wages

The output series by Álvarez-Nogal and Prados de la Escosura (2013) uses price and real wage data in a demand function approach to estimate annual primary sector output. Whether this series accurately reflects short-term output fluctuations depends on nominal rigidities.

Here, we use model simulations to show that, for the degree of price and wage rigidity we estimate, the output series by Álvarez-Nogal and Prados de la Escosura (2013) indeed accurately describes short-term fluctuations in real output. The model we use is a modified version of the baseline model that features a primary and non-primary sector. The model is calibrated analogously to the baseline model. We use the calibrated model to simulate a time series of primary consumption, as well as all the time series needed for obtaining

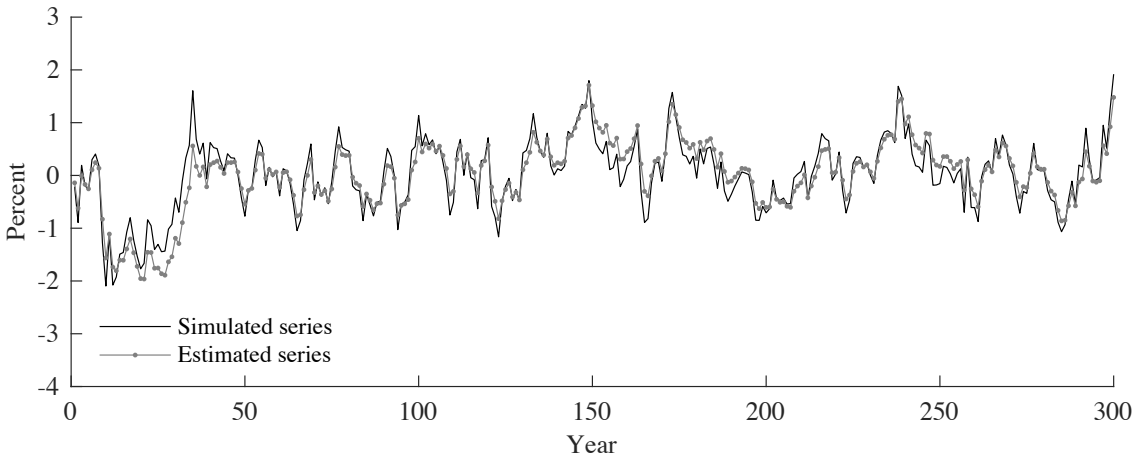
the demand function estimate of primary consumption. Álvarez-Nogal and Prados de la Escosura (2013) calculate the latter as

$$c_t^P = \tilde{\epsilon} p_t^P + \tilde{\gamma} p_t^{NP} + \tilde{\mu} m_t, \tag{A.9}$$

where c_t^P is the estimated primary consumption, p_t^P the model simulated primary goods price, and p_t^{NP} the simulated non-primary goods price. m_t denotes household wage income, proxied by the simulated household wage rate. The elasticities $\tilde{\epsilon}, \tilde{\gamma}, \tilde{\mu}$ are calibrated as in Álvarez-Nogal and Prados de la Escosura (2013)'s baseline output estimate.

Figure A.8 shows the result. It compares the simulated time series of primary consumption (black line) to the demand function approach based estimate of the same series (gray line with marker). As can be seen, the short-term fluctuations are very similar across both series. Thus, given our baseline model parameter estimates, the demand function approach accurately captures short-term output fluctuations in output.

Figure A.8: Primary consumption: Model simulation vs. demand function estimate



Notes: In percent deviations from steady state.

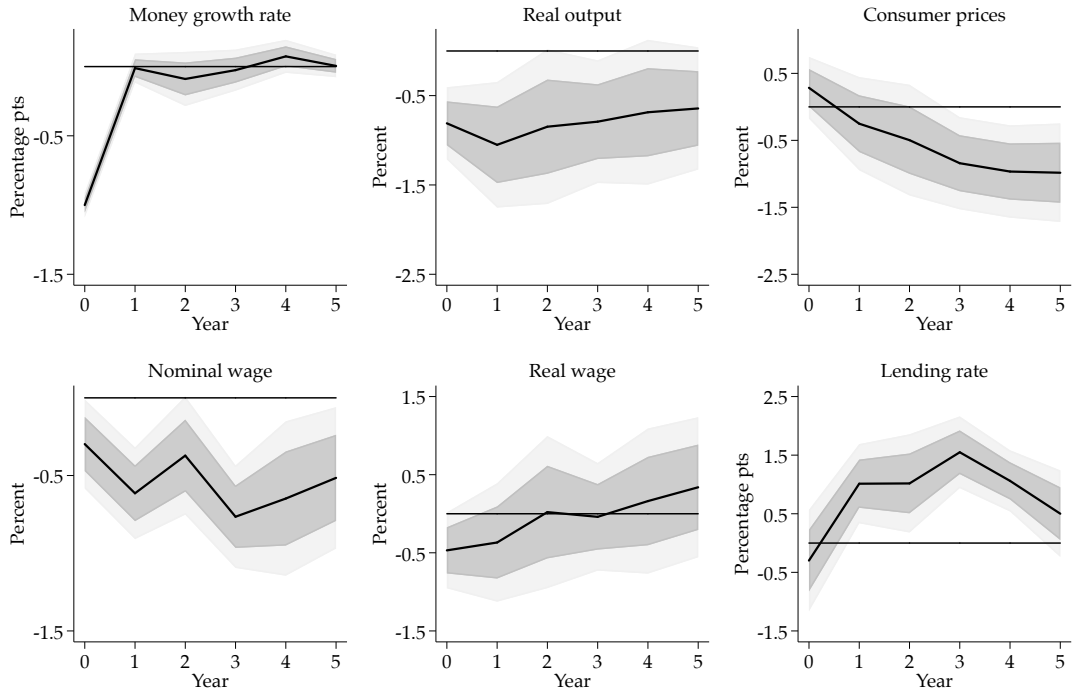
B. Additional results

Table B.1: Silver inflows and Spanish exports

Spanish export (growth rate)	-0.05		-0.05
	(0.04)		(0.04)
L.Spanish export (growth rate)		-0.02	-0.02
		(0.04)	(0.04)
F-statistic (p-value)	0.18	0.67	0.39
R squared	0.11	0.01	0.12
Observations	18	17	17

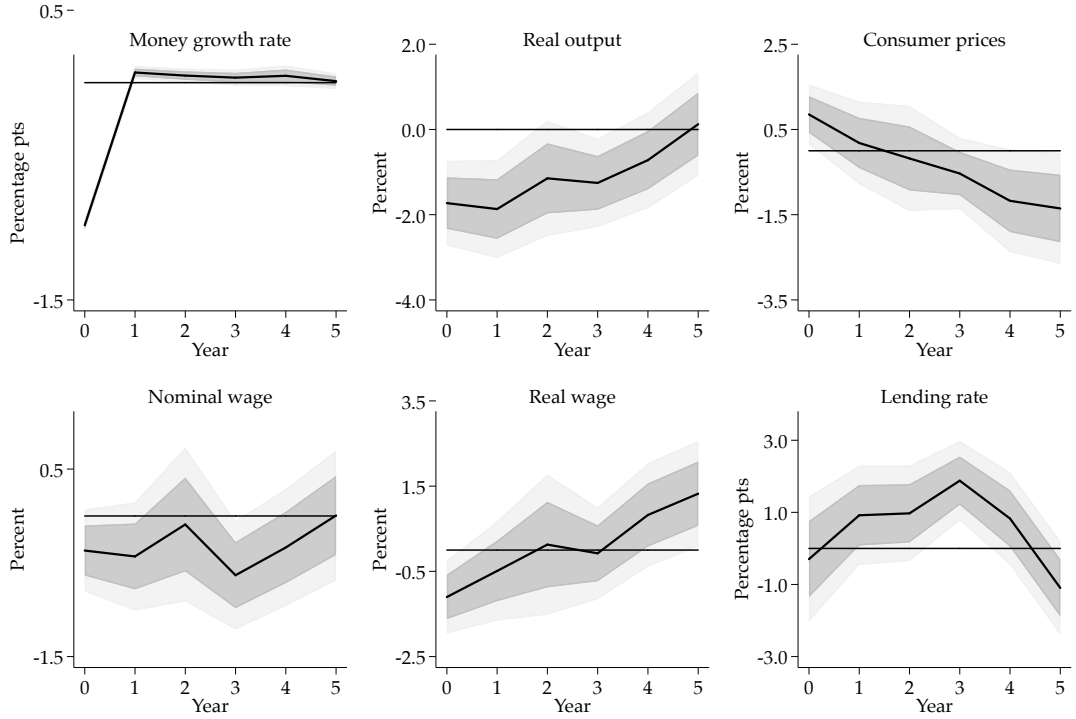
Notes: * 90%, ** 95%, *** 99%. Standard errors in parentheses. Dependent variable – silver inflow growth rate. Independent variables – Spanish export value growth rate. Export data from Esteban (1981).

Figure B.1: Impulse responses for negative 1 ppt money growth shock (parsimonious)



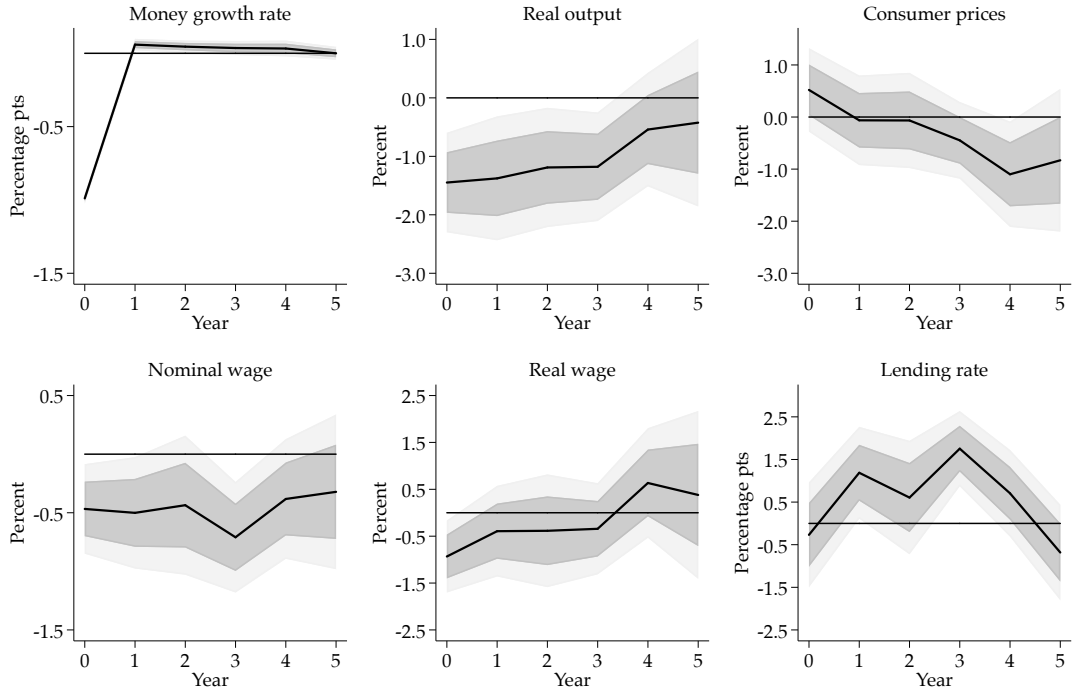
Notes: Parsimonious specification. Local projections including only contemporaneous money shock variables among the regressors: money loss, money salvaged, money captured (no lags/leads).

Figure B.2: Impulse responses for negative 1 ppt money growth shock (excl. conflicts)



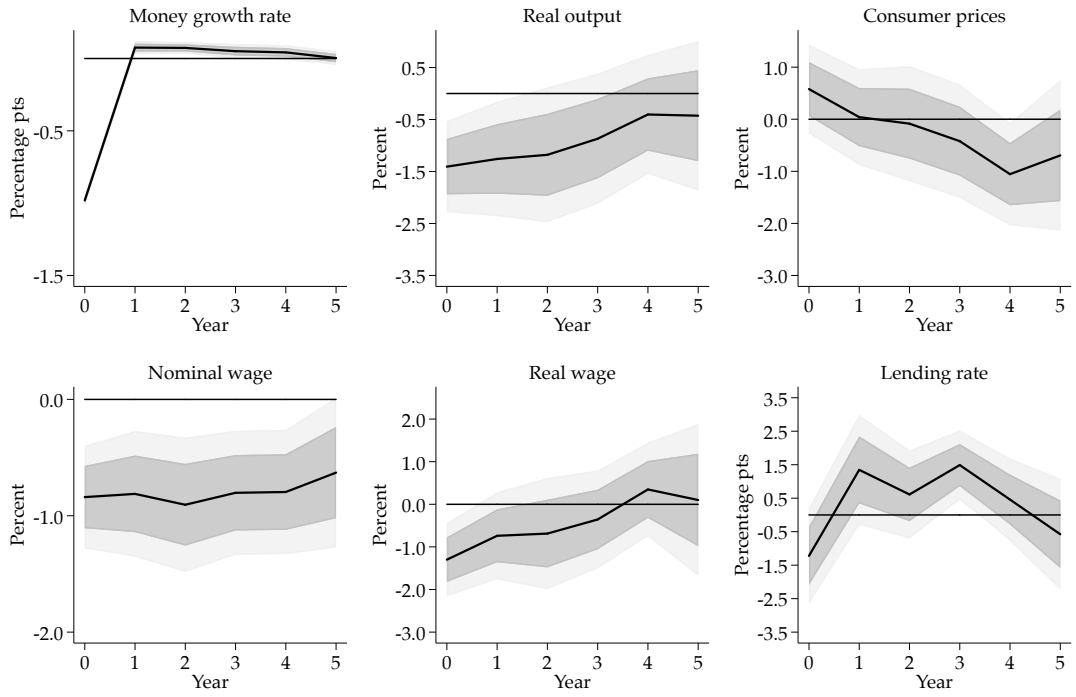
Notes: Results based on a specification that allows money shocks caused by combat or capture events to develop different effects, by including an interaction term between the money shock and a conflict dummy.

Figure B.3: Impulse responses for negative 1 ppt money growth shock (pre-1780 sample)



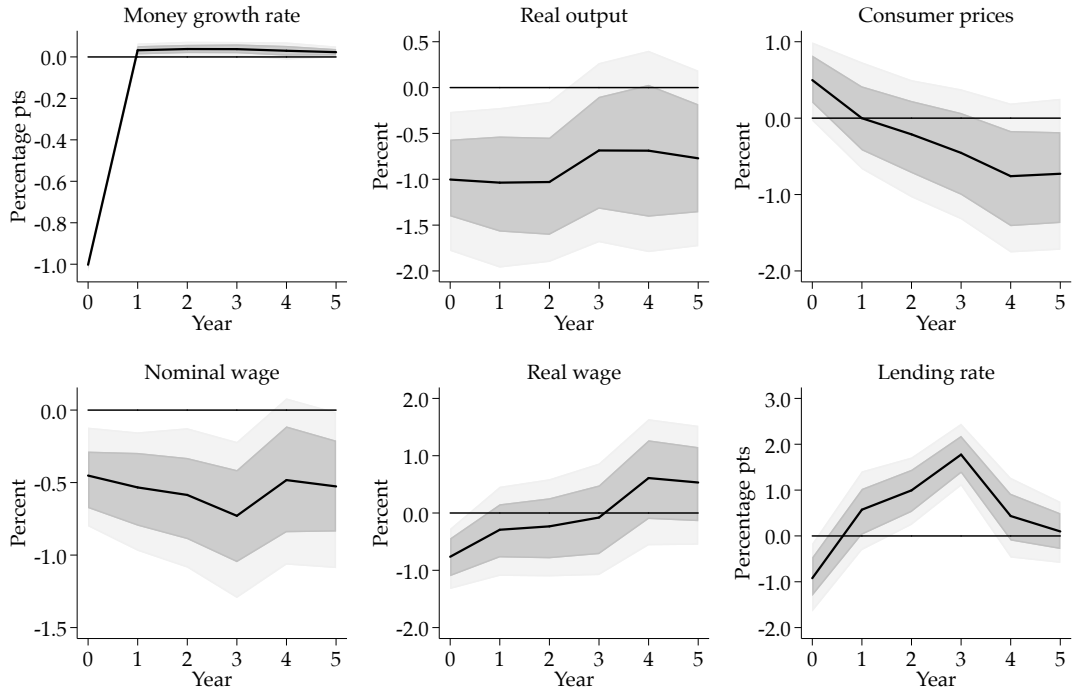
Notes: Local projections based on pre-1780 sample.

Figure B.4: Impulse responses for negative 1 ppt money growth shock (excl. Vellón years)



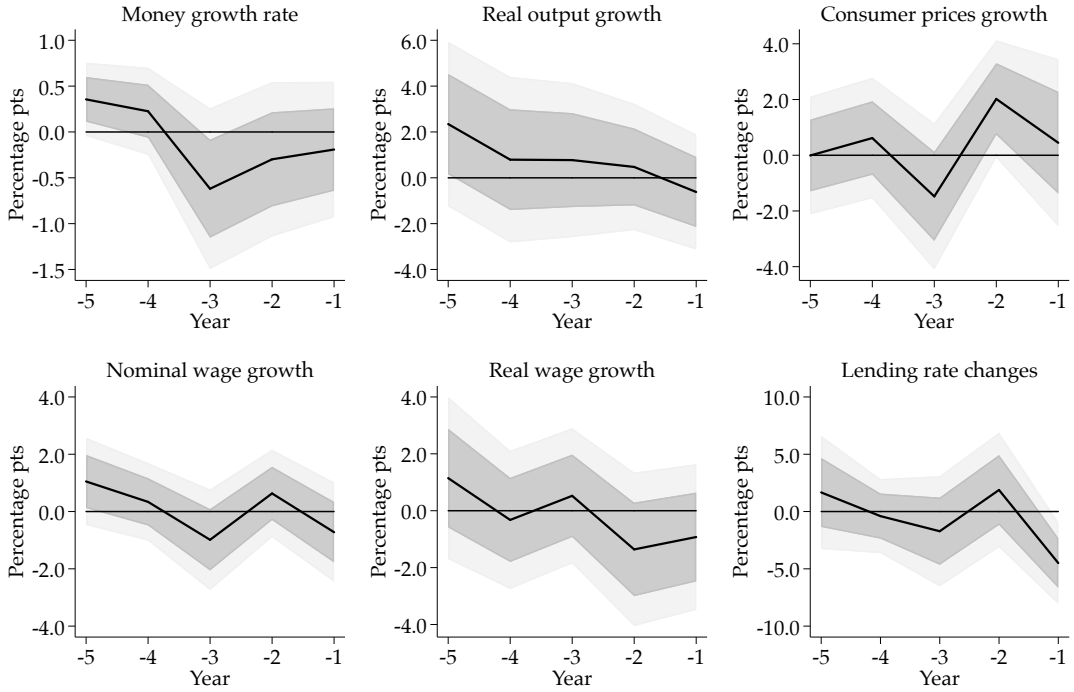
Notes: Results based on a specification that allows money shocks to develop different effects during Vellón years (1619-1659), by including an interaction term between the money shock and a Vellón year dummy.

Figure B.5: ARDL model results (negative 1 ppt money growth shock)



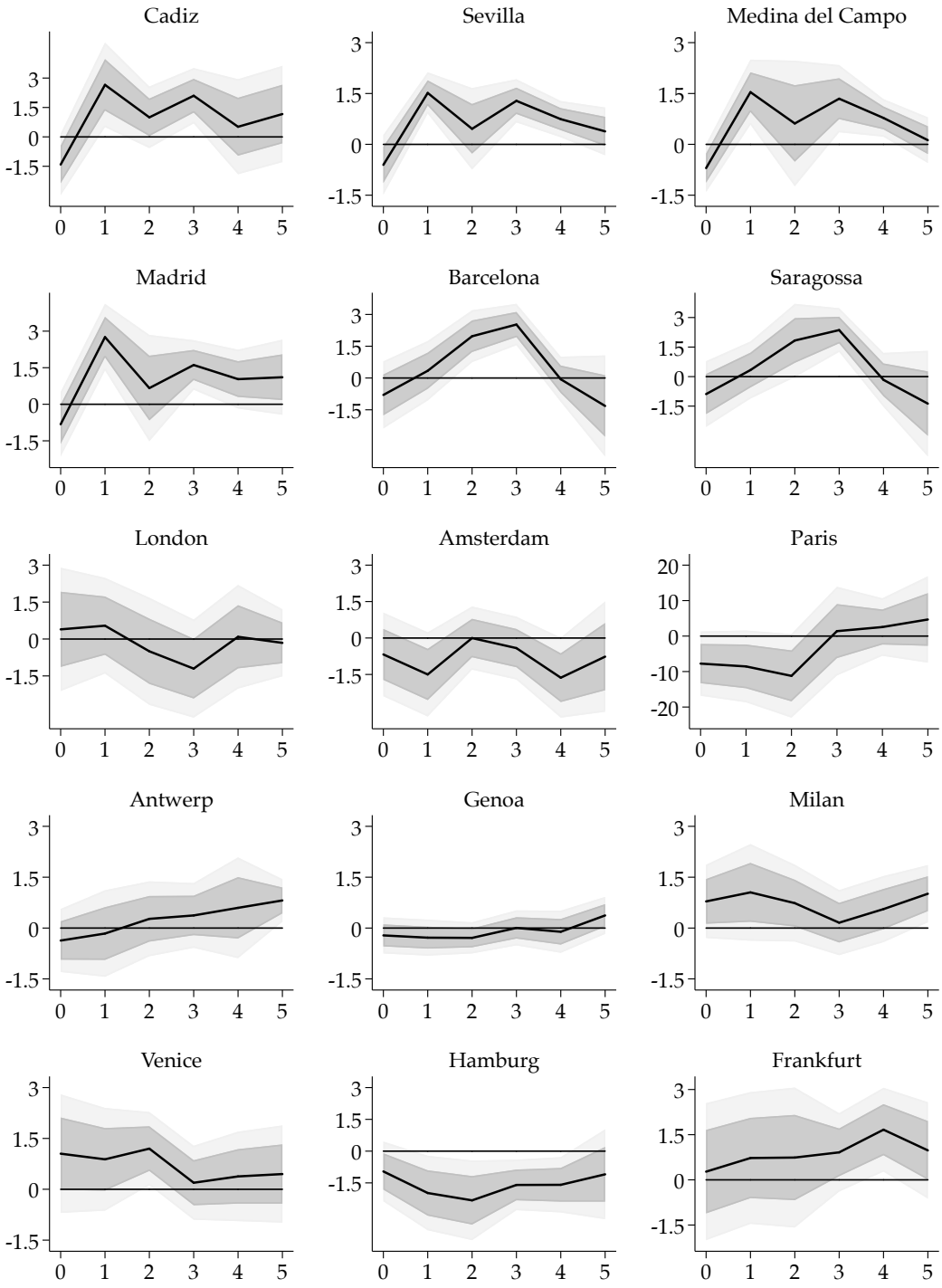
Notes: Autoregressive distributed lag (ARDL) model based on 4 lags of all regressors, as well as 4 leads of all exogenous regressors.

Figure B.6: Pre-event analysis



Notes: Black line – average growth rate of variables prior to maritime disaster years compared to non-disaster years.

Figure B.7: European interest rate responses (negative 1 ppt money growth shock)



Notes: In percentage points. The figure shows the IRFs for those cities where the available data allows for the construction of long-run lending rate estimates. The lending rate series for each of these cities straddles at least 13 maritime disaster events. Lending rates in some non-Spanish cities actually decreased. This might point towards a "run to safety" response, in which lending retracted from Spain and moved to safer destinations in the aftermath of maritime disasters.

C. Model

This section presents the details on our theoretical model. The model is a styzlied DSGE model of the early modern Spanish economy, with nominal price and wage rigidities in the fashion of Calvo (1983), credit frictions as in Bernanke et al. (1999), and a regular stream of money inflows that resembles the arrival of silver shipments to Spain. Throughout the section, lower-case variables denote real variable, e.g. $w_t = W_t/P_t$.

C.1. Baseline non-linear model

We will first present the nonlinear equation system. All agents' optimization problems and the resulting first order conditions are described in detail.

Money stock

The money stock M^s evolves as

$$M_t^s = M_{t-1}^s(1 + g_M)\exp(\epsilon_{M,t}),$$

where g_M is the money stock's trend growth rate, $\epsilon_{M,t}$, an i.i.d. shock with mean zero. Money inflows, $\Delta_{M,t} = M_t^s - M_{t-1}^s$, are received by entrepreneurs – the model economy's equivalent to Spanish merchants.

Households

An infinitely lived representative household derives utility from consumption, c_t, and disutility from labor, l_t. A money-in-utility approach is used to reflect the liquidity service provided by money holdings, M_t. The representative household maximizes its expected discounted utility subject to the budget constraint

$$\begin{aligned} &\max_{\{c_{t+k},l_{t+k},M_{t+k},D_{t+k}\}_{k=0}^{\infty}} \mathbb{E}_t\left\{\sum_{k=0}^{\infty}\frac{c_{t+k}^{1-\sigma}}{1-\sigma} + \zeta\frac{(M_{t+k}/P_{t+k})^{1-\psi}}{1-\psi} - \xi\frac{l_{t+k}^{1+\upsilon}}{1+\upsilon}\right\} \\ \text{subject to} \quad &P_t c_t + D_t + M_t = W_t l_t + R_{t-1}D_{t-1} + M_{t-1} + \Omega_t. \end{aligned}$$

The consumption good, c_t, is a Dixit-Stiglitz composite of a variety of differentiated goods produced by final goods producers: $c_t = \left(\int_0^1 c_t(j)^{\frac{\mu_p-1}{\mu_p}}\mathrm{d}j\right)^{\frac{\mu_p}{\mu_p-1}}$, where μ_p denotes the elasticity of substitution, and j is the producer index, $j \in [0,1]$. The corresponding consumer price is an average of the differentiated goods' prices: $P_t = \left[\int_0^1 P_t(j)^{1-\mu_p}\mathrm{d}j\right]^{\frac{1}{1-\mu_p}}$

and the household's demand schedule for goods of the producer j is $c_t(j) = \left(\frac{Pt(j)}{P_t}\right)^{-\mu_p} c_t$. The first order condition yields the conventional consumption Euler equation

$$c_t^{-\sigma} = \beta R_t \mathbb{E}_t \left\{ \frac{c_{t+1}^{-\sigma}}{\Pi_{t+1}} \right\}, \tag{C.1}$$

with gross inflation $\Pi_t \equiv P_t / P_{t-1}$. The labor supply satisfies

$$w_t = \frac{\xi l_t^v}{c_t^{-\sigma}}. \tag{C.2}$$

The optimal level of real money holdings is pinned down by

$$\zeta (\frac{M_t}{P_t})^{-\psi} = c_t^{-\sigma} \left(1 - \frac{1}{R_t}\right). \tag{C.3}$$

Guilds

To model wage rigidity in a tractable way, we assume that homogenous household labor is differentiated by guilds, who act as an early modern analogue to labor unions. In particular, a guild – indexed by $i \in [0,1]$ – buys homogenous labor from households at wage W_t, differentiates it at no costs, and sells the differentiated labor to the intermediate goods producer on a monopolistically competitive labor market at a nominal wage $\tilde{W}_t(i)$. The intermediate goods producer employs a composite of union labor $\tilde{l}_t = \left(\int_0^1 l_t(i)^{\frac{\mu_w - 1}{\mu_w}} \mathrm{d}i \right)^{\frac{\mu_w}{\mu_w - 1}}$. The demand schedule for union i's labor is thus $l_t(i) = \left(\frac{\tilde{W}_t(i)}{\tilde{W}_t}\right)^{-\mu_w} \tilde{l}_t$, where $\tilde{W}_t$ is the average wage level, defined as $\tilde{W}_t = \left[\int_0^1 \tilde{W}_t(i)^{1-\mu_w} \mathrm{d}i \right]^{\frac{1}{1-\mu_w}}$. Guilds are owned by households, and they maximize their expected future profits, discounted by the households' stochastic discount factor (SDF). Wage rigidity is modeled as in Calvo (1983). Each period, a fraction $(1 - \theta_w)$ of guilds can re-optimize their wages, while the rest increases wages by the steady state inflation Π. When given the opportunity, guilds set their wages optimally, taking into accout the labor demand schedule

$$\begin{aligned} \max_{\tilde{W}_t^*(i)} \quad & \mathbb{E}_t \sum_{k=0}^{\infty} \left\{ \tilde{\beta}_{t,t+k} \, \theta_w^k \left[\tilde{W}_t^*(i) \Pi^k - W_{t+k} \right] l_{t+k}(i) \right\} \\ \text{s.t.} \quad l_{t+k}(i) \quad = \quad & \left(\frac{\tilde{W}_t^*(i) \Pi^k}{\tilde{W}_{t+k}} \right)^{-\mu_w} \tilde{l}_{t+k}, \end{aligned}$$

where $\tilde{\beta}_{t,t+k}$ denotes households' SDF for nominal payoffs ($\tilde{\beta}_{t,t+k} \equiv \beta^k \frac{\lambda_{t+k}/P_{t+k}}{\lambda_t / P_t}$). The SDF takes variations in households' marginal utility of wealth, $\lambda_t \equiv c_t^{-\sigma}$, into account. Optimal wage setting is described with the help of the auxiliary variables $F_{w,t}$ and $K_{w,t}$

by the following equations

$$F_{w,t} = \lambda_t \tilde{l}_t \left(\frac{\tilde{w}_t^*}{\tilde{w}_t}\right)^{1-\mu_w} + \beta\theta_w \mathbb{E}_t \Pi_{w,t+1} \left(\frac{\tilde{w}_t^*}{\tilde{w}_t}\frac{\tilde{w}_{t+1}}{\tilde{w}_{t+1}^*}\frac{\Pi}{\Pi_{w,t+1}\Pi_{t+1}}\right)^{1-\mu_w} F_{w,t+1}, \quad \text{(C.4)}$$

$$K_{w,t} = \lambda_t \frac{\mu_w}{\mu_w - 1}\frac{w_t}{\tilde{w}_t}\tilde{l}_t \left(\frac{w_t^*}{\tilde{w}_t}\right)^{-\mu_w} \quad \text{(C.5)}$$

$$+\beta\theta_w \mathbb{E}_t \Pi_{w,t+1} \left(\frac{\tilde{w}_t^*}{\tilde{w}_t}\frac{\tilde{w}_{t+1}}{\tilde{w}_{t+1}^*}\frac{\Pi}{\Pi_{w,t+1}\Pi_{t+1}}\right)^{-\mu_w} K_{w,t+1},$$

$$K_{w,t} = F_{w,t}, \quad \text{(C.6)}$$

with $\Pi_{w,t} \equiv \tilde{w}_t/\tilde{w}_{t-1}$. The aggregate wage dynamic is given by

$$1 - \theta_w \left(\frac{\Pi}{\Pi_{w,t}\Pi_t}\right)^{1-\mu_w} = (1-\theta_w)\left(\frac{\tilde{w}_t^*}{\tilde{w}_t}\right)^{1-\mu_w}, \quad \text{(C.7)}$$

$$\Delta_{w,t} = \theta_w \Delta_{w,t-1} \left(\Pi_{w,t}\Pi_t/(\Pi)\right)^{\mu_w} + (1-\theta_w)\left(\frac{\tilde{w}_t^*}{\tilde{w}_t}\right)^{-\mu_w}, \quad \text{(C.8)}$$

where $\Delta_{w,t} = \int_0^1 \left(\frac{\tilde{w}_t(i)}{\tilde{w}_t}\right)^{-\mu_w} \mathrm{d}i$ denotes the wage dispersion.

Capital goods producers

Capital goods producers use the composite of final goods as input, i_t, to produce new capital, Δ_t^k. In doing so they incur a resource cost, $\Psi\left(\frac{i_t}{k_{t-1}}\right)k_{t-1}$.[23] The produced capital is then sold to entrepreneurs on a competitive market. Taking the nominal price for capital, Q_t, as given, capital goods producers maximize their period profits by choosing the amount of investment inputs

$$\max_{i_t} Q_t \left[i_t - \Psi\left(\frac{i_t}{k_{t-1}}\right)k_{t-1}\right] - P_t i_t.$$

This gives rise to the following equilibrium nominal price of capital

$$Q_t = P_t \left[1 - \Psi'\left(\frac{i_t}{k_{t-1}}\right)\right]^{-1}. \quad \text{(C.9)}$$

The economy's aggregate capital stock evolves according to

$$k_t = k_{t-1}(1-\delta) + \Delta_t^k, \quad \text{(C.10)}$$

where δ denotes the capital depreciation rate, and $\Delta_t^k = i_t - \Psi\left(\frac{i_t}{k_{t-1}}\right)k_{t-1}$.

[23] In steady state $\Psi\left(\frac{i}{k}\right) = 0$.

Entrepreneurs and financing

Entrepreneurs are risk-neutral producers that turn pre-existing capital, k_{t-1}, and newly hired labor, $\tilde{l}_t$, into intermediate goods, $\tilde{y}_t$

$$\tilde{y}_t = z_t k_{t-1}^{\alpha} \tilde{l}_t^{1-\alpha}. \tag{C.11}$$

z_t is an idiosyncratic productivity shock and α denotes the capital share of income. The timing is as follows: At the end of period $t-1$ an entrepreneur decides how much to invest in capital. The purchase of capital is partly financed internally, out of the entrepreneur's net worth N_{t-1}, and partly externally, through credit B_{t-1} obtained from financial intermediaries: $Q_{t-1}k_{t-1} = N_{t-1} + B_{t-1}$. The cost of external financing is described by the average nominal lending rate $\tilde{R}_{t-1}^k$. At the beginning of period t, an entrepreneur observes the idiosyncratic productivity shock and decides how much labor to employ. Produced intermediate goods are then sold on a competitive market at price $\tilde{P}_t$. Taking the market price for their output as given, entrepreneurs choose capital and labor to maximize their net worth. This give rise to labor demand that satisfies

$$\tilde{W}_t = (1-\alpha)\frac{\tilde{P}_t \tilde{y}_t}{\tilde{l}_t}. \tag{C.12}$$

The marginal return on capital in period t is the ex post output, net of labor costs and capital depreciation, relative to the cost of purchasing capital. Using the labor demand function, we have

$$R_t^k = \frac{\alpha \tilde{P}_t \tilde{y}_t + Q_t k_{t-1}(1-\delta)}{Q_{t-1}k_{t-1}}. \tag{C.13}$$

Optimal capital stock acquisition at the end of period t requires that the real expected marginal borrowing cost equals the expected return on capital

$$\mathbb{E}_t\left[\frac{\tilde{R}_t^k}{\Pi_{t+1}}\right] = \mathbb{E}_t\left[\frac{\alpha \tilde{P}_{t+1}/P_{t+1}\tilde{y}_{t+1} + Q_{t+1}/P_{t+1}k_t(1-\delta)}{Q_t/P_t k_t}\right]. \tag{C.14}$$

At the end of period t, profits and money inflows accrue to the entrepreneur's net worth. Only a random fraction $\gamma \in (0,1)$ of entrepreneurs carry over their accumulated net worth to the next period and continue with their business. The rest exit, and consume their net worth. Altogether, the aggregate net worth of entrepreneurs evolves according

to

$$\begin{aligned} N_t &= \gamma \left[R_t^k Q_{t-1} k_{t-1} + \Delta_t^M - \tilde{R}_{t-1}^k \left(Q_{t-1} k_{t-1} - N_{t-1} \right) \right] \\ &= \gamma \left[\tilde{R}_{t-1}^k N_{t-1} + \left(R_t^k - \tilde{R}_{t-1}^k \right) Q_{t-1} k_{t-1} + \Delta_t^M \right], \end{aligned} \tag{C.15}$$

where R_t^k denotes the average marginal return on capital ($R_t^k = \frac{\alpha \tilde{P}_t \tilde{y}_t + Q_t k_{t-1}(1-\delta)}{Q_{t-1} k_{t-1}}$), $\tilde{R}_{t-1}^k \left(Q_{t-1} k_{t-1} - N_{t-1} \right)$ are the debt servicing costs that entrepreneurs pay to financial intermediaries, and Δ_t^M is the money inflow that entrepreneurs receive.[24]

Financial intermediaries receive deposits from households, on which they pay the risk-free deposit rate R_t, and they lend to entrepreneurs. Entrepreneurs' idiosyncratic productivity shocks give rise to idiosyncratic default probabilities. To discover how much a defaulting entrepreneur can repay, financial intermediaries incur a cost. Following Bernanke et al. (1999), this state verification problem gives rise to a positive external finance premium, $\tilde{R}_t^k / R_t > 1$, that increases in leverage

$$\frac{\tilde{R}_t^k}{R_t} = \Lambda \left(\frac{Q_t k_t}{N_t} \right), \tag{C.16}$$

where $\Lambda(\cdot)$ denotes a function that increases in its argument.

Retailers

Retailers – indexed by j – buy intermediate goods $\tilde{y}$ at price $\tilde{P}_t$, differentiate them at no costs, and sell them to households and capital goods producer through a monopolistically competitive goods market. Retailers are owned by households and they maximize their expected future profits, discounted by the households' SDF. Price rigidity is modeled as in Calvo (1983). Each period, a fraction $(1 - \theta_p)$ of retailers can re-optimize their prices, while the rest adjusts prices by the steady state consumer price inflation, Π. The retailers' optimization problem is thus analogous to that of guilds

$$\begin{aligned} \max_{P_t^*(j)} \quad & \mathbb{E}_t \sum_{k=0}^{\infty} \left\{ \tilde{\beta}_{t,t+k} \, \theta_p^k \left[P_t^*(j) \Pi^k - \tilde{P}_{t+k} \right] y_{t+k}(j) \right\} \\ \text{s.t.} \quad y_{t+k}(j) &= \left(\frac{P_t^*(j) \Pi^k}{P_{t+k}} \right)^{-\mu_p} y_{t+k}, \end{aligned}$$

where y_t denotes the composite of final goods $y_t = \left(\int_0^1 y_t(j)^{\frac{\mu_p - 1}{\mu_p}} \mathrm{d}j \right)^{\frac{\mu_p}{\mu_p - 1}}$. The optimal price setting behavior of firms is described with the help of the auxiliary variables F_t and

[24] Note that in the model, households do not receive any silver inflows. This is because we classify households that participated in the transatlantic colonial trade as entrepreneurs in the model.

K_t

$$F_t = \lambda_t y_t \left(\frac{P_t^*}{P_t}\right)^{1-\mu_p} + \beta\,\theta_p\,\mathbb{E}_t\left(\frac{P_t^*}{P_t}\frac{P_{t+1}}{P_{t+1}^*}\frac{\Pi}{\Pi_{t+1}}\right)^{1-\mu_p} F_{t+1}, \tag{C.17}$$

$$K_t = \lambda_t \frac{\mu_p}{\mu_p - 1}\frac{\tilde{P}_t}{P_t}\left(\frac{P_t^*}{P_t}\right)^{-\mu_p} y_t + \beta\,\theta_p\,\mathbb{E}_t\left(\frac{P_t^*}{P_t}\frac{P_{t+1}}{P_{t+1}^*}\frac{\Pi}{\Pi_{t+1}}\right)^{-\mu_p} K_{t+1}, \tag{C.18}$$

$$K_t = F_t. \tag{C.19}$$

Aggregate consumer prices evolve according to

$$1 - \theta_p\left(\frac{\Pi}{\Pi_t}\right)^{1-\mu_p} = (1-\theta_p)\left(\frac{P_t^*}{P_t}\right)^{1-\mu_p}, \tag{C.20}$$

$$\Delta_t = \theta_p \Delta_{t-1}\left(\Pi_t/\Pi\right)^{\mu_p} + (1-\theta_p)\left(\frac{P_t^*}{P_t}\right)^{-\mu_p}, \tag{C.21}$$

where $\Delta_t = \int_0^1 \left(\frac{P_t(j)}{P_t}\right)^{-\mu_p} \mathrm{d}j$ denotes the price dispersion.

Equilibrium

We analyze a symmetric equilibrium where the markets for goods, labor, financial assets, and money clear. Since entrepreneurs do not hold money, money market clearing requires household money demand to equal money supply

$$M_t = M_t^S. \tag{C.22}$$

The production function of guilds implies $l_t = \int_0^1 l_t(i)\mathrm{d}i$. This together with the labor demand schedule leads to

$$l_t = \Delta_{w,t}\tilde{l}_t. \tag{C.23}$$

The production function of retailers implies $\tilde{y}_t = \int_0^1 y_t(j)\mathrm{d}j$. Using the goods demand schedule, we have

$$\tilde{y}_t = \Delta_t y_t. \tag{C.24}$$

Labor market clearing in the intermediate goods sector requires

$$\tilde{y}_t = k_{t-1}^{\alpha}\tilde{l}_t^{1-\alpha}. \tag{C.25}$$

Final goods market clearing is described by

$$y_t = c_t + i_t + c_{e,t}, \tag{C.26}$$

where $c_{e,t} = (1-\gamma)n_t$ is the consumption by entrepreneurs existing in period t. Financial market clearing requires

$$D_t = Q_t k_t - N_t. \tag{C.27}$$

C.2. Log-linearized system of equations

This section describes the log-linearized equation system. The equations are derived as first-order Taylor approximations of the nonlinear equation around the model's non-stochastic steady state. We normalize the steady state output to 1.

Equations C.28 to C.30 describe household behaviors, equations C.31 to C.32 the aggregate wage dynamics, equations C.33 to C.42 describe the production sector, and equation C.43 is the goods market clearing condition. Finally, equations C.44 to C.46 describe the evolution of the money stock and the exogenous processes.

$$\hat{c}_t = \mathbb{E}_t \hat{c}_{t+1} - \frac{1}{\sigma}\left(\hat{R}_t - \mathbb{E}_t \hat{\Pi}_{t+1}\right) \tag{C.28}$$

$$\sigma \hat{c}_t - \psi \hat{m}_t = \frac{1}{R-1}\hat{R}_t \tag{C.29}$$

$$v\hat{l}_t + \sigma \hat{c}_t = \hat{w}_t \tag{C.30}$$

$$\hat{\Pi}_{w,t} = \hat{\tilde{w}}_t - \hat{\tilde{w}}_{t-1} \tag{C.31}$$

$$\hat{\Pi}_{w,t} + \hat{\Pi}_t = \beta \mathbb{E}_t(\hat{\Pi}_{w,t+1} + \hat{\Pi}_{t+1}) - \kappa_w \left(\hat{\tilde{w}}_t - \hat{w}_t\right) \tag{C.32}$$

$$\hat{R}^k_t + \hat{q}_{t-1} - \hat{\Pi}_t = (1-\chi)\left(\hat{\tilde{p}}_t + \hat{y}_t - \hat{k}_{t-1}\right) + \chi \hat{q}_t \tag{C.33}$$

$$\hat{\tilde{R}}^k_t - \hat{R}_t = \Xi\left(\hat{q}_t + \hat{k}_t - \hat{n}_t\right) \tag{C.34}$$

$$\hat{\tilde{R}}^k_t = \mathbb{E}_t \hat{R}^k_{t+1} \tag{C.35}$$

$$\hat{k}_t = (1-\delta)\,\hat{k}_{t-1} + \delta\,\hat{i}_t \tag{C.36}$$

$$\hat{q}_t = \Upsilon\left(\hat{i}_t - \hat{k}_{t-1}\right) \tag{C.37}$$

$$\hat{n}_t = \frac{\gamma R^k q k}{n\Pi}\left(\hat{R}^k_t - \hat{\tilde{R}}^k_{t-1}\right) + \frac{\gamma R^k}{\Pi}\left(\tilde{R}^k_{t-1} + \hat{n}_{t-1} - \hat{\Pi}_t\right) + \frac{\gamma \delta_m}{n}\hat{\delta}_{m,t} \tag{C.38}$$

$$\hat{c}_{e,t} = \hat{n}_t \tag{C.39}$$

$$\hat{\tilde{w}}_t = \tilde{\hat{p}}_t + \hat{y}_t - \hat{l}_t \tag{C.40}$$

$$\hat{y}_t = \alpha \hat{k}_{t-1} + (1-\alpha)\hat{l}_t \tag{C.41}$$

$$\hat{\Pi}_t = \beta \mathbb{E}_t \hat{\Pi}_{t+1} + \kappa_p \tilde{\hat{p}}_t \tag{C.42}$$

$$\hat{y}_t = \frac{c}{y}\hat{c}_t + \frac{i}{y}\hat{i}_t + \frac{c_e}{y}\hat{c}_{e,t} \tag{C.43}$$

$$\hat{\delta}_{m,t} = \hat{m}_{t-1} - \hat{\Pi}_t + \frac{1+g_m}{g_m}\epsilon_{m,t} \tag{C.44}$$

$$\hat{m}_t = \hat{m}_{t-1} - \hat{\Pi}_t + \epsilon_{m,t} \tag{C.45}$$

$$\epsilon_{m,t} = \rho_m \epsilon_{m,t-1} + \eta_{m,t} \tag{C.46}$$

Ψ'' is the second derivative of the capital production cost function $\Psi(\cdot)$, evaluated at the steady state. Λ' is the first derivative of the credit supply function $\Lambda(\cdot)$, evaluated at the steady state. The following are auxiliary parameters:

$$\kappa_p = \frac{(1-\theta_p)(1-\beta\theta_p)}{\theta_p} \tag{C.47}$$

$$\kappa_w = \frac{(1-\theta_w)(1-\beta\theta_w)}{\theta_w} \tag{C.48}$$

$$\chi = \frac{(1-\delta)q}{\alpha\tilde{p}y/k + (1-\delta)q} \tag{C.49}$$

$$\Upsilon = \Psi'' \frac{i}{kq} \tag{C.50}$$

$$\Xi = \frac{\Lambda'}{\Lambda}\frac{qk}{n} \tag{C.51}$$

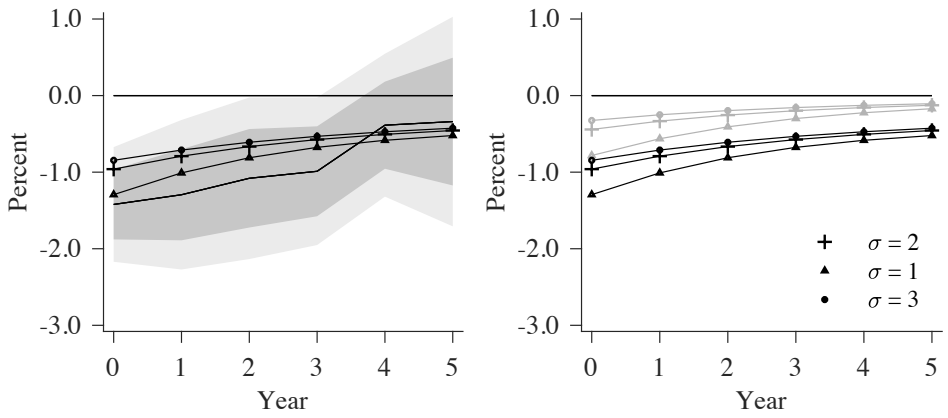
D. Additional model results

D.1. Alternative calibration

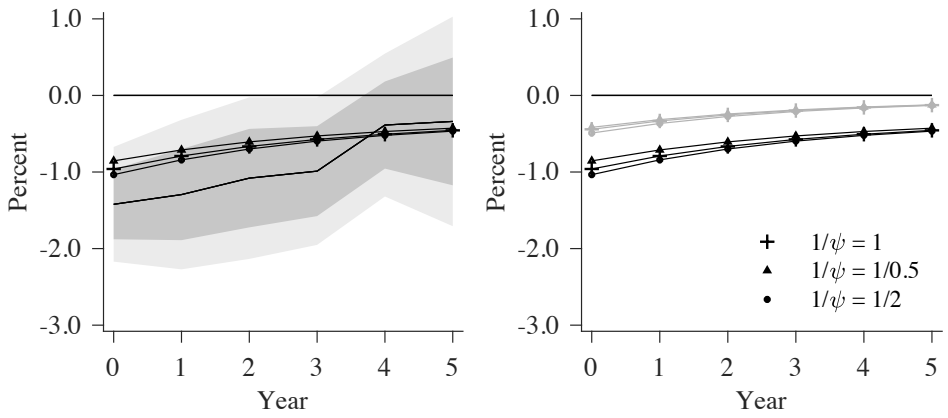
In this subsection, we examine the robustness of our results with respect to alternative calibrations. In particular, we explore alternative values for the inverse of the intertemporal elasticity of consumption substitution ($\sigma = 1$ or 3), the interest elasticity of money demand ($1/\psi = 0.5$ or 2), the capital adjustment cost parameter ($\Upsilon = 0.6$ or 1), as well as the Frisch elasticity of labor supply ($1/\upsilon = 2$ or 5). We change the parameter of interest one at a time, while keeping the other parameters at their calibrated values as described in the main text. The slopes of the price and wage Phillips curves, as well as the leverage elasticity of the external finance premium, are estimated with IRF-matching for each alternative calibration. Figure D.1 shows that our result is robust with respect to plausible changes in these parameters.

Figure D.1: Decomposition based on alternative calibrations (-1 ppt money growth shock)

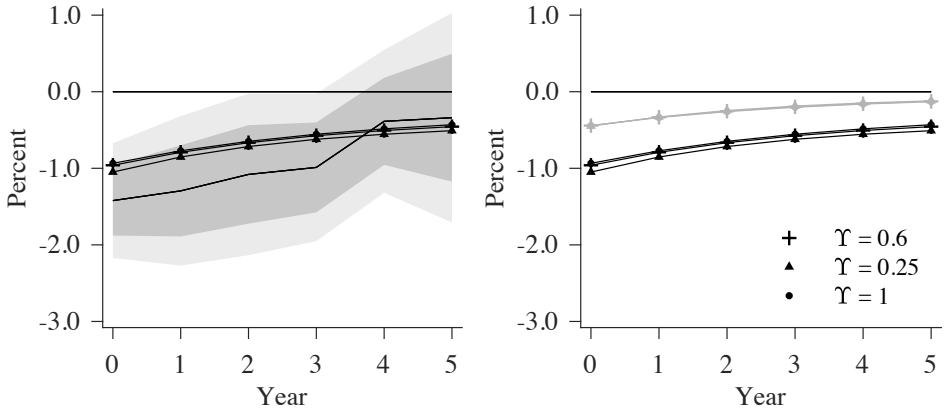
(a) Alternative elasticity of intertemporal consumption substitution: σ



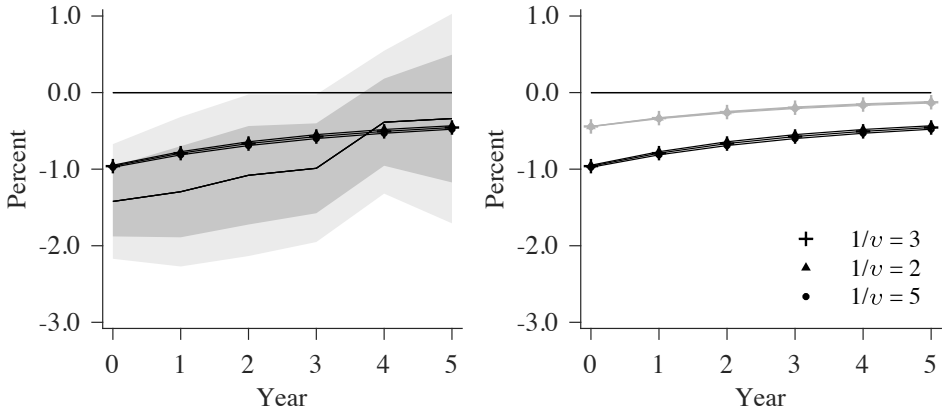
(b) Alternative money demand elasticity: $1/\psi$



(c) Alternative capital adjustment cost: Υ



(d) Alternative Frisch elasticity of labor supply: $1/\upsilon$



Notes: Left hand side: Solid lines – empirical impulse responses. Gray areas – empirical 1 standard deviation and 90% confidence bands. Solid lines with markers – model impulse responses. Right hand side: Black solid lines with markers – impulse response with nominal rigidities and credit frictions. Gray solid lines with markers – impulse response without credit frictions.

D.2. Alternative modeling

In this subsection, we explore the robustness of our results with respect to alternative modeling. In particular, we examine three alternative scenarios: (1) prices and wages are backward indexed; (2) lending rates are set one period in advance; (3) explicit modeling of the crown's spending. We describe in the following each alternative model in turn. Each of these alternatives is calibrated and estimated using IRF-matching as described in the main text. D.2 compares the empirical and the model impulse responses and shows the decomposition of the transmission channels. Our results are robust with respect to these alternative modeling strategies.

(1) Backward indexation

As in Christiano et al. (2005), we look at a variant of the Calvo nominal rigidities with backward indexation. For wages, each period a fraction $(1-\theta_w)$ of guilds can re-optimize, while the rest increases wages by last period's nominal wage inflation. For prices, each period a fraction $(1-\theta_p)$ of final goods producers can re-optimize, while the rest increases prices by last period's nominal price inflation.

(2) Lagged lending rates

We assume that lending rates are set one period in advance. This allows us to analyze rigidity in the setting of lending rates, as a potential explanation for the lagged empirical response of lending rates. The rate $\tilde{R}^k_{t-1}$, set in $t-1$, denotes the cost for external financing in period t. Thus, the aggregate net worth of entrepreneurs evolves according to

$$N_t = \gamma \left[R^k_t Q_{t-1} k_{t-1} + \Delta_{s,t} - \tilde{R}^k_{t-2} \left(Q_{t-1} k_{t-1} - N_{t-1} \right) \right]. \tag{D.1}$$

The lending rate, $\tilde{R}^k_{t-1}$, depends on the expected risk-free rate and the aggregate leverage ratio

$$\tilde{R}^k_{t-1} = \mathbb{E}_{t-1} \left[\Lambda \left(\frac{Q_t k_t}{N_t} \right) R_t \right]. \tag{D.2}$$

(3) Fiscal spending

In our baseline model, we abstract from the fact that part of the silver arrival went to the Spanish Crown instead of the private sector. Here, we will augment our baseline model with a "fiscal sector" to examine the effect of silver-financed fiscal spending.

We assume that a fraction ω of the yearly silver arrival went to the crown directly, while the rest was received by the private sector (merchants).[25] Letting G_t denote the part of fiscal spending that fluctuates with the Crown's silver income, we have

$$\omega \Delta_{M,t} = G_t \tag{D.3}$$

The final goods market clearing condition, after taking into account the Crown's spending, becomes

$$y_t = c_t + i_t + c_{e,t} + \bar{g} + g_t, \tag{D.4}$$

where $\bar{g}$ denotes the part of fiscal spending not fluctuating with silver inflows. The

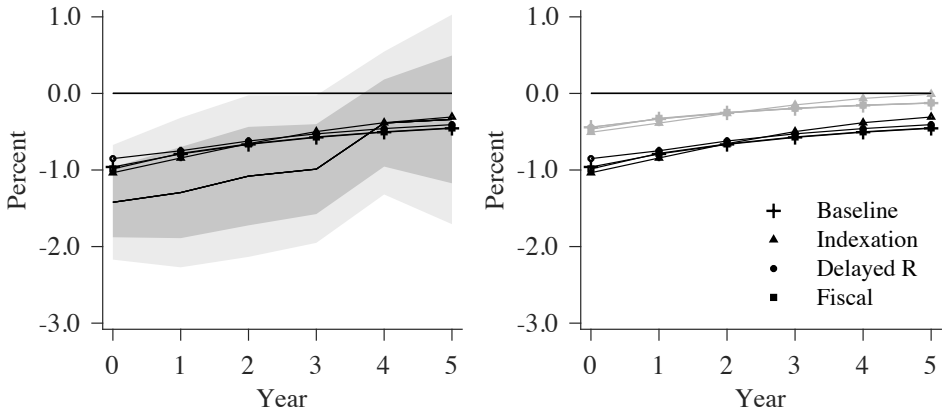
[25] It was highly probably that the Crown spent only a fraction of this silver income on domestic final goods, while the rest is spent the money on foreign goods. This is only taken into account by our empirical estimate of the silver stock, which aims to capture any outflow of silver from Spain.

aggregate net worth of entrepreneurs evolves according to

$$N_t = \gamma \left[R_t^k Q_{t-1} k_{t-1} + (1-\omega)\Delta_t^M - \tilde{R}_{t-1}^k \left(Q_{t-1} k_{t-1} - N_{t-1} \right) \right]. \tag{D.5}$$

We calibrate $\omega = 0.2$, reflecting the royal fifth - the tax upon silver arrival. $\frac{\bar{g}}{y}$ is set to 0.02, the average ordinary expenditure to output ratio between 1566 - 1596 (Drelichman and Voth, 2010). Concerning the fiscal expenditure that relates to silver revenues, we have $\frac{g}{y} = \omega \frac{\delta_M}{y}$.

Figure D.2: Decomposition based on alternative modelling (-1 ppt money growth shock)



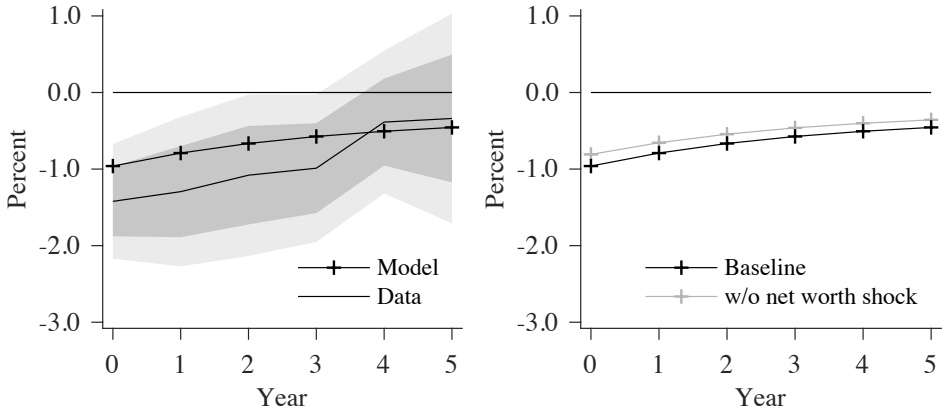
Notes: Left hand side: Solid line – empirical impulse response. Gray areas – empirical 1 standard deviation and 90% confidence bands. Right hand side: Black solid line with markers – impulse response with nominal rigidities and credit frictions; gray solid line with markers – impulse response without credit frictions. The baseline results and the results from three alternative models are plotted: (1) Indexation – a model with backward indexation; (2) Delayed R – a model with one-period lagged lending rate; (3) Fiscal – a model with Crown spending.

D.3. Alternative decomposition: Wealth vs. liquidity

Money shocks affect the economy in two ways. First, because money constitutes financial wealth, a money shock entails a shock to the level of wealth. Second, because money constitutes the most liquid form of wealth, a money shock alters the liquidity composition of an economy's wealth. In this section we analyze the relative importance of these two aspects of money shocks for our non-neutrality result.

The loss of silver shipments entailed a net worth loss for the merchants who were the owners of that silver. Such a drop in merchant net worth has real effects, because it tightens the financial constraint and thus gives rise to higher lending rates and less investment. To see how important the initial merchant net worth loss is for the overall real output

Figure D.3: Wealth shock vs. liquidity composition (negative 1 ppt money growth shock)



Notes: Left hand side: Solid line – empirical output IRF. Solid line with + markers – model output IRF. Gray areas – empirical 1 standard deviation and 90% confidence bands. Right hand side: Black solid line with markers – baseline impulse response. Gray solid line with markers – impulse response without merchant wealth loss.

response, we calculate a counterfactual model IRF in which there is no initial merchant wealth loss. More specifically, we let the negative money shock enter the household budget constraint instead of the merchant budget constraint (a negative helicopter drop). Absent a financial friction on the household side such a lump-sum wealth reduction has no impact on the model dynamics. Thus, redirecting the money loss from merchants to households eliminates the wealth level aspect of the money shock. The resulting counterfactual IRF delineates the effect that the money shock develops through its effect on the liquidity composition of the economy's wealth.

The right panel of Figure D.3 shows the result. The solid black line with markers is the baseline model response. The gray line is the counterfactual response with no initial merchant net worth loss. The difference between these two responses indicates the importance of the wealth reduction aspect of the money shock. Only a very small part of the real output response can be explained by the initial merchant wealth loss. The large remainder of the real output response is due to the money shock's liquidity composition effect. Note that the liquidity composition effect encompasses the nominal rigidity effect and that part of the credit channel effect that is not due to the initial merchant wealth loss, i.e. the amplification effect associated with lower merchant profitability due to the drop in liquidity.

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