The University of Manchester

Economics

Discussion Paper

Series

EDP-1904

The Real Effects of Monetary Expansions: Evidence from a Large-Scale Historical Experiment

Nuno Palma

February 2019

Updated August 2021

Economics

School of Social Sciences

The University of Manchester

Manchester M13 9PL

The real effects of monetary expansions: evidence from a large-scale historical experiment

Nuno Palma*

Department of Economics, University of Manchester

Instituto de Ciências Sociais, Universidade de Lisboa

CEPR

Forthcoming in: ***Review of Economic Studies***

Abstract

The discovery of massive deposits of precious metals in America during the early modern period caused an exogenous monetary injection to Europe's money supply. I use this episode to identify the causal effects of money. Using a panel of six European countries, I find that monetary expansions had a material impact on real economic activity. The magnitudes are substantial and persist for a long time: an exogenous 10% increase in the production of precious metals in America measured relative to the European stock leads to a front-loaded response of output and, to a lesser extent, inflation. There was a positive hump-shaped response of real GDP, with a cumulative increase up to 0.9% six to nine years later. The evidence suggests that this is because prices responded to monetary injections with considerable lags.

Keywords: Identification in macroeconomics, early modern monetary injections, liquidity effects, wealth effects, monetary non-neutrality.

JEL codes: E40, E50, N13

*This paper is a revised version of a chapter of my PhD dissertation and previously circulated with the titles: "The existence and persistence of liquidity effects: evidence from a large-scale historical natural experiment" and "The existence and persistence of monetary non-neutrality: evidence from a large-scale historical natural experiment". I am thankful to the editor, Michèle Tertilt, and four annoymous referees for many suggestions that have improved the paper. I have also benefited from discussions with Adrien Auclert, James Banks, David Baqaee, Tim Besley, Stephen Billington, Roberto Bonfatti, Vasco C. Botelho, Pedro Carneiro, Carlos Javier Charotti, Jeremie Cohen-Setton, Luís Costa, Yao Chen, Adriana Cornea-Madeira, Velichka Dimitrova, Jeremiah Dittmar, Rodney Edvinsson, Rui Esteves, Giuseppe Felloni, Nicholas Gachet, Rachel Griffith, Alastair Hall, Ethan Ilzetzki, Alejandra Irigoin, Réka Juhász, Kıvanç Karaman, João Madeira, Paolo Malanima, Nick Mayhew, Myroslav Pidkuyko, Steve Pischke, Angela Redish, Nick Ridpath, Albrecht Ritschl, Joan Rosés, João S. Silva, Kevin Sheedy, Manuel M. Tarrio, Silvana Tenreyro, Akos Valentinyi, François Velde, Chris Wallace, Felix Ward, Jan Luiten van Zanden, as well as participants at several seminars and conferences. Kendall W. Brown kindly shared the files of the late John TePaske with me, while Joël Félix shared French mint output data, Noel Johnson temperature data, Ulrich Pfister unpublished GDP series for Germany, and Leandro Prados de la Escosura annual data for Spain. Special thanks are due to Adam Brzezinski for outstanding research assistance. Financial support from Fundação para a Ciência e a Tecnologia (CEECIND/04197/2017) is gratefully acknowledged. The replication package for this paper is deposited at: https://doi.org/10.5281/zenodo.4727681

1. Introduction

Is monetary policy capable of stimulating economies, and if so, to what degree and duration? This question is difficult to answer empirically because monetary policy is endogenous. In this paper, I argue that early modern discoveries and production of precious metals in America can be used to identify the macroeconomic effects of monetary shocks. Variation in the availability of precious metals caused by the discovery of American mines of silver and gold led to exogenous monetary variation in Europe. This historical natural experiment allows for the identification of the effects of changes in money supply on the macroeconomy.

I find significant and strong effects of monetary injections on the real economy. A 10% increase in the production of precious metals measured relative to the monetary stock caused real GDP in Europe to rise by a cumulative 0.9% in the following years, with the peak effect reached six to nine years later. Prices responded to monetary injections with considerable lags relative to nominal GDP. While nominal GDP responded to a 10% shock by about 1.5% six years later, the response of prices was only 0.8%. Prices increased gradually over time, and their continued response meant that the response of real GDP declined after year nine, producing a hump-shaped response of real GDP over time.

To reach these conclusions, I use data that spans a very long horizon (1531 to 1790). My results rely on local projections (Jordà, 2005), and I find evidence for strong and long-lasting effects of money on economic activity using three different approaches: the whole panel; country-specific estimates; and an IV procedure. The latter also shows directly that production of precious metals caused increases in mint output, which in turn affected the real economy. To account for the potential endogeneity of mining activities, I show on both historical and statistical grounds that the discovery and production of precious metals in America was exogenous to short-term variation in the state of the European economy, and that people were unable to forecast well how much was being imported to Europe.

My paper relates to a long-standing debate surrounding how to identify the causal effects of monetary policy, given the two-way causality between the state of the economy and decisions taken by monetary authorities.[1] The literature on the identification problem caused by money endogeneity goes back at least to Tobin (1970)'s criticism of Friedman and Schwartz (1963), but the debate has not converged to a consensus. Recently, the empirical macroeconomics literature has adopted different strategies. Some studies attempt to recover structural shocks through a careful "narrative approach" (Romer and Romer, 1989, 2004), while others follow a more technical approach, using recursive VARs (Christiano, Eichenbaum, and Evans, 1999) or interest rate futures surprises on FOMC dates as instruments (Gertler and Karadi, 2015). While

[1] Empirical monetary economics suffers from a challenging identification problem: variation in the money supply or interest rates is not exogenous to the state of the economy. Central banks respond to the state of the economy and try to influence, as well as respond to, agents' expectations. This joint causality leads to a fundamental identification problem that prevents straightforward inference. Since central banks tend to pump up the monetary base during, or when they anticipate, a recession, simple correlations can suggest that positive changes in money have no effect, or even a negative effect, on output even if the exact opposite is true in a causal sense.

many of these studies conclude that money matters, much disagreement remains with respect to the timing, transmission mechanism, and impact magnitude. The estimated effects on aggregate output range from essentially zero, through moderate, to large.[2] Additionally, most strategies have been criticized on identification grounds.[3] While structural VARs remain the most popular choice in the literature, Romer (2018, p. 225) writes that they "have not found a compelling way of addressing the problem that the Federal Reserve may be adjusting policy in response to information it has about future economic developments that the VARs do not control for."[4]

My contribution to this literature concerns a period and context different from that of today, but with the advantage that exogeneity is warranted. I show that internal validity holds: income and price variation in Europe was the consequence, not the cause, of the discovery and varying levels of production in American mines. I make no external validity claims about the size or persistence of the effects for modern economies; nevertheless, my finding that prices were sticky and that there were strong monetary effects complements the view in macroeconomics that the economy is reactive to monetary policy. The two closest papers to mine in the literature are Velde (2009), who studies an overnight change in the money supply in eighteenth century France, and a paper that studies what happened to the Spanish economy when maritime disasters prevented the arrival of the Atlantic silver fleets (Brzezinski et al., 2019).

The rest of this paper is organized as follows. Section 2 provides the historical background and introduces the data, shedding light on why variation in production levels of American mines is as-if random with respect to the state of the European economy. Section 3 identifies the effects of additional availability of money on GDP and prices. Section 4 defends the validity of the natural experiment on statistical grounds. Finally, section 5 concludes.

2. Historical background and data

In this section, I explain why the amount of precious metals produced in the Americas can be used as a source of exogenous variation in the European money stock. In what follows, I first explain the nature of the commodity money system in early modern Europe and how it was affected by the arrival of precious metals from the colonies. I then describe the nature of the mining pursuits in America and argue on historical grounds that annual variation in precious metals production was exogenous to the state of the European economy. I then give details on the data to be used in the next sections of the paper.

[2]The first group includes Uhlig (2005) and Sims and Zha (2006); the second, Christiano, Eichenbaum, and Evans (1999, 2005) and Coibion (2012); and the third, Romer and Romer (1989, 2004), Angrist and Kuersteiner (2011), Cloyne and Hürtgen (2016), Barakchian and Crowe (2013), and Wolf (2020). See also Arias et al. (2019) and Jordà et al. (2020).

[3]See, for instance, Leeper (1997), Chari, Kehoe, and McGrattan (2008), Stock and Watson (2018), Arias et al. (2019) and Wolf (2020). Recent reviews of the literature on monetary policy shocks and their effects include Ramey (2016), Stock and Watson (2017), and Nakamura and Steinsson (2018a). The latter shows that even the best evidence we have for non-neutrality of money is fragile.

[4]There is, however, a recent literature on the central bank information channel: Jarociński and Karadi (2020); Miranda-Agrippino and Ricco (2018); Nakamura and Steinsson (2018b).

2.1. The early modern commodity money system

The early modern monetary system was a commodity money system. Precious metals, chiefly silver and gold, were a required input for the production of coinage.[5] In general, circulation was by tale within national boundaries, though in the case of gold and silver coins (but not copper) there was a large component of intrinsic value.[6] There were no central banks in the modern sense, but there was a form of monetary policy: within limits, the monetary authority controlled the rate at which private agents could transform precious metals into currency.

The availability of precious metals hence mattered for how much new coin was minted. Challis (1992, p.431), for instance, argues that "it was not unknown for the Mint to have to strike more in a single year than it had in the previous five ... but these variations were outside of the Mint's control since it depended entirely on what importers chose to deliver to it for coining, on windfalls of captured treasure, and on decisions by the government." The latter in turn depended at least in part on the government's perception of the availability of precious metals. Money was produced under a free minting system: anyone could bring any quantity of silver or gold to the mint and receive in return coins (Redish, 2000; Sargent and Velde, 2002). Mints were run by private entrepreneurs to whom the ruler leased this right. They charged about 5% in brassage (the costs of minting) and seigniorage – though in England, these were not charged after 1666 (Challis, 1992, pp.338, 351, 745-6).

Other means of exchange existed, but their importance should not be exaggerated for the early modern period. Less liquid than coin but also functionally money, these included forms of "inside money" such as bills of exchange and banknotes. Table 1 illustrates the case of England, by 1700 arguably the most advanced economy in the sample. Even there, coin retained central importance throughout the early modern period, especially considering that until 1797, banknotes and most other means of payment were only available in large denominations (O'Brien and Palma, 2020). In continental Europe, coin generally played an even more important role: as late as the 1860s, "on the continent . . . specie accounted for somewhere between one-half and three-quarters of the money supply" (Flandreau, 2004, p.3).[7] Inside money was endogenous and complemented the more liquid and widely accepted bullion-based currency (Nightingale, 1990). They were not a substitute for coin over the long term because of credibility constraints (Palma, 2018b).

Although the supply of precious metals was inelastic, and precious metals were a critical input in the production of money, it was nonetheless true that, as today, the total quantity of

[5] I am here referring to legal tender coinage alone, rather than money more broadly. Coins based on copper, whether provided by governments or private parties, were akin to fiat money, but could only be used for small transactions; see, for instance, Sargent and Velde (2002).

[6] The nominal or face value of coinage which defined its purchasing power differed from the intrinsic value of coins. In the countries under consideration here, coins typically circulated by tale, not by weight, so the face value was above the market value of the metals, should they be melted (and of course, this kept them in circulation). But the value of silver or gold coins was usually close to intrinsic value (Karaman et al., 2019).

[7] In Spain, even as late as 1875 gold and silver coins still made up 85% of the Spanish money supply (Tortella and Ruiz, 2013, p.78).

money was potentially endogenous to the state of the economy. This was because the decision of the monetary authority to engage in forms of monetary manipulation such as debasements were responses to macroeconomic and political conditions. But there were binding constraints to these actions (Palma, 2018b) and hence the shortage of precious metals that characterized much of fifteenth century Europe had negative implications for the total amount of liquidity in the economy (Nightingale, 1990). The situation was about to change with the discovery of vast amounts of gold and silver in the Americas.

	1600 (Mayhew)	1688 (Cameron)	1700 (Capie)	1750 (Cameron)	1750 (Capie)	1790 (Capie)
Coin	3.5	10	7	15	18	44
Bank of England notes	0	0	1.5	4.3	4	8
Other notes (country banknotes)	0	0	0	0.7	1	4
Bank balances at the bank of England	0	0	0	1.9	-	-
Other means of payment	1	10	n/a	18.1	n/a	n/a
Total (M2)	4.5	20	>8.5	40	>23	>56

Table 1: Estimates for the components of English nominal money supply. Unit: millions of £. Sources: Mayhew (2013), Capie (2004), and Cameron (1967). The category "other means of payment" includes Cameron's £6m in government tallies plus £2m in inland bills in 1688 and £3.1m in deposits in private banks in 1750.

2.2. The determinants of American precious metals production

The key identification assumption in this paper is that the discovery and production of precious metals in America was exogenous to short-term variation of the state of the European economy. I now show that it is reasonable to assume this from a historical point of view. In Section 4 below, I additionally defend this assumption statistically, using weather shocks as an instrument for the state of the European economy.

The New World was the primary source of precious metals production in the world during the early modern period (Barret, 1990). Figure 1 shows the location and mining quantities across the Americas. The mines were privately owned and operated (Hamilton, 1934, p.15).[8] The Spanish and Portuguese Crowns received only a percentage of the overall value of production in the form of taxes.[9] In the words of Irigoin (2018, p.276), "at least 70% of the treasure imports to Spain was made of privately owned silver." The enormous quantities imported to Europe dwarfed the

[8]See also Elliott (2006, p.93), Bakewell (1971, p.181), and Boxer (1962, p.52).

[9]This corresponded to either 1/10 in Mexico (and in Peru after the 1720s) or 1/5 (in Peru prior to the 1720s, and in Brazil; though during 1735-1751, in Brazil taxes were paid depending on the number of slaves, but then reverted to one fifth again). Additionally, one could add occasional Crown-sequestered property and forced loans on arrival; the latter were usually paid back, though not necessarily in time or at market interest rates. Still, all considered, we can consider 30% as an upper bound for what belonged to the state.

initially available stocks (Table 2).[10] Much of the overall early modern production occurred in Mexico. Potosí (located in modern Bolívia) and other areas of the Spanish viceroyalty of Peru also mattered considerably, especially from the mid-sixteenth to the mid-seventeenth century (TePaske, 2010).[11] Overall, Mexico and Peru were responsible for over 99% of the production of silver in the whole of the American continent during the early modern period. In turn, Brazil was responsible for most of the production of gold, though gold production also surged in eighteenth-century Mexico. But the history of mining up to the eighteenth century was overwhelmingly one of silver (Figure 2), despite Christopher Columbus's early obsession with searching for gold – and the early success of finding moderate quantities in the Caribbean (Vilar, 2011).

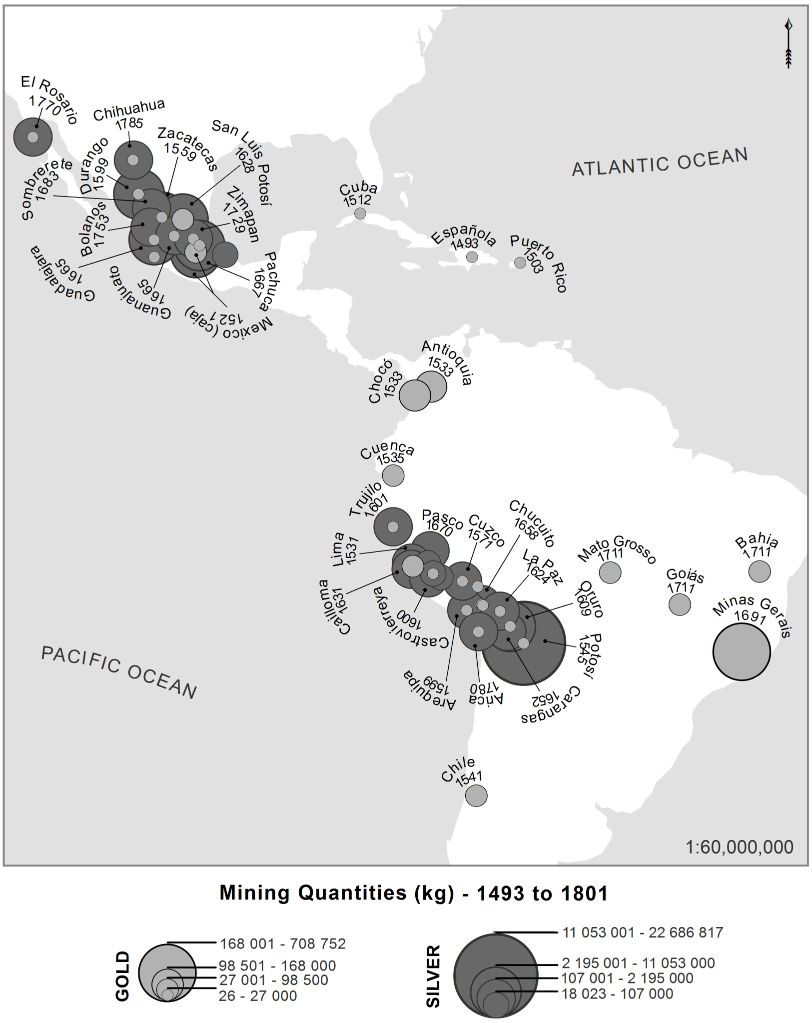

Figure 1: Location of the mines, initial date of records and mining quantities. Source for the underlying data: TePaske (2010).

[10]Table 2 shows the quantities imported to Europe, ignoring those which stayed in the Americas or which were exported directly from America to Asia through the Pacific, although the latter also had important consequences for European economies by stimulating trade with Asia (Palma and Silva, 2016). Notice also that the bulk of the value of the early modern Atlantic imports consisted of precious metals, with other colonial goods such as sugar playing a much more marginal role (Brzezinski et al., 2019).

[11]The same is still true, though to a slightly lesser degree, if precious metals are measured in real value terms.

	Fine silver	Gold	Gold, silver-equivalent	Total, silver-equivalent
Initial stock, World (1492)	3,600	297	3,267	6,867
Initial stock, Europe (1492)	828	68	751	1,579
Imports to Europe				
1500-1600	7,500	150	1,650	9,150
1600-1700	26,168	158	2,212	28,380
1700-1800	39,157	1,400	21,000	60,157
Total Imports	72,825	1,708	24,862	97,687

Table 2: Bullion stocks and flows in Europe (in tonnes, i.e. metric tons). Sources: Stocks from Velde and Weber (2000, p.1230) and Palma (2019, p.3). Flows from Morineau (2009, p.570). Bimetallic ratios from Barret (1990, p.238).

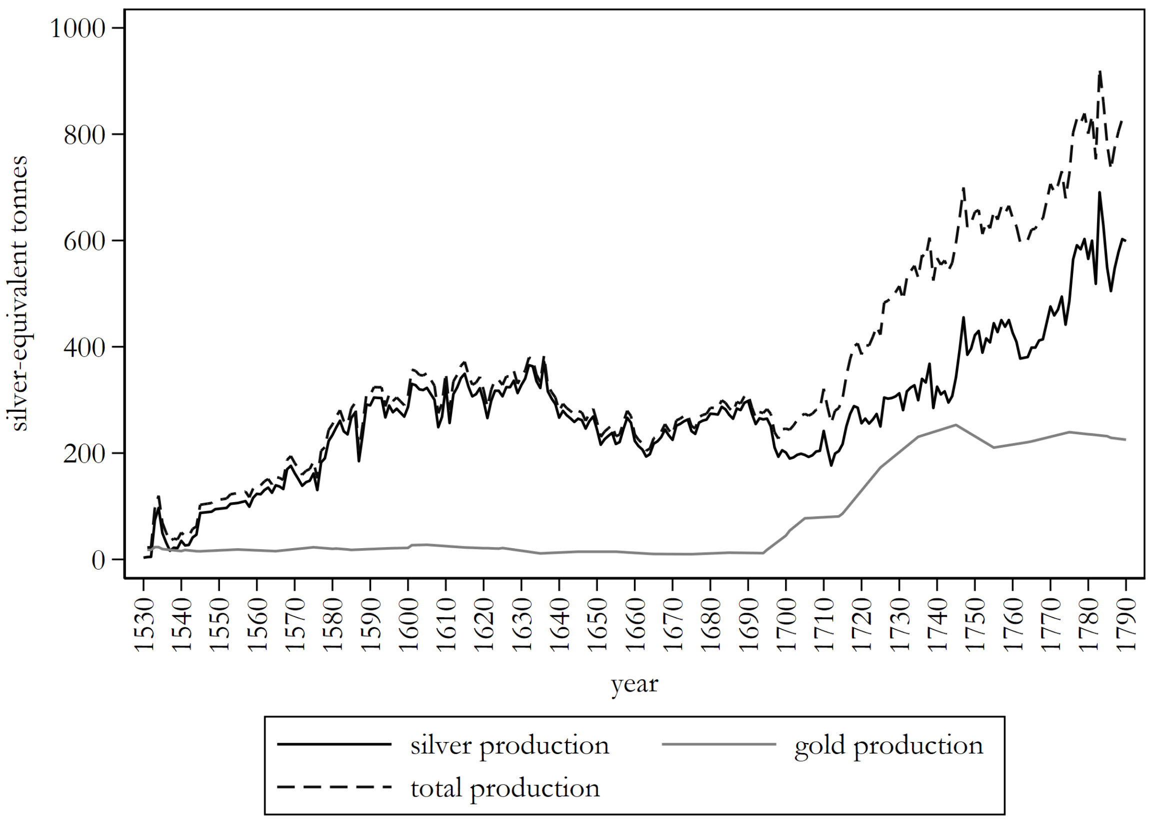

Figure 2: Gold and silver production in the Americas. Sources: TePaske (2010) and Jara (1966); bimetallic ratios from Barret (1990, p.238).

Mining output in the Americas was exogenous to the European economy, as it depended on the discovery of new mines, many of which were extremely productive by comparison with their European counterparts. Prior to the discovery of the American continent, the European economy was characterized by a dearth of silver and gold, and mining in Europe may have been endogenous to the European economy. The silver mines of central Europe (mainly in Saxony, Bohemia, and Hungary), had reopened in the fourteenth century in response to demand. They became uncompetitive towards the mid-sixteenth century once precious metals from Potosí and the rest of America increasingly became available. The situation improved with the start of mining operations in the Americas; within decades, the initial stock of precious metals available in Europe was dwarfed by imports from the colonies. Mining in the Americas was different from that in Europe: faced with the possibility of finding a new mountain of silver or gold, spot prices for precious metals mattered little in inducing additional search or mining intensity effort. The decisions were instead based on constraints such as access to capital and the feasibility of entering unknown territories under reasonable conditions of security and health (Bacci, 2010).

The history of the European colonization of Latin America is largely a history of the search for sources of precious metals. Over and over again, explorers searched – usually in vain – for multiple El Dorados. But there is little to suggest that investors or explorers decided to go ahead or cancel an expedition based on short-term variation in the macroeconomic conditions of European economies. Explorations were a risky investment with high sunk and fixed costs, but low variable costs. Under this scenario, variation in success of exploration, as well as technological innovations, will lead to exogenous variation in precious metal production. This was never a decision on the margin. It was impossible to know in advance where precious metals might exist, even when some characteristics associated with the presence of precious metals were known, such as high altitudes or mountains. Explorers could and did ask the natives, but more often than not the result was disappointing. The relatively late discovery of the rich gold mines of Brazil in the late seventeenth century is illustrative. Speculation about the possibility of silver or gold mines existing in the interior had been going on for about two centuries before any were found. By 1677, the former governor of Rio de Janeiro testified to the national authorities (*Conselho Ultramarino*) that no gold existed in Brazil (Figueiredo, 2012, p.64, 234). Explorers had been nearby in the previous century and even as recently as 1674-82 (Boxer, 1962, pp. 35-6). The accidental nature of the discovery of precious metals is repeatedly mentioned in the historical literature.[12] All available evidence suggests that the timing of gold discoveries was not anticipated.[13]

The mining intensity decisions were also exogenous to the state of the European economy, because the intensity of mining was driven by availability of technology and local cost conditions, not demand. Once a rich mine was found and fixed costs were paid, for a long time the value was well above the cost of operation, and price variations would have been insufficient to induce changes in the intensity of mining. In the short term, due to capital, entrepreneurial, and physical constraints, the marginal cost was increasing with output, implying that mines did not get exhausted at once.[14] Furthermore, while today most mining operations are run by large corporations such as Rio Tinto, in colonial America mines were managed by individuals who

[12]See, for instance, Bakewell (1971, p. 7) or Boxer (1962, pp. 254-6).

[13]Placebo tests discussed below confirm this empirically: future mining does not affect current GDP.

[14]Costs dictated mining intensity, since compared with them, the price which dictates revenue was of second order. This is analogous to modern mining operations in developing countries, for which "operations are expensive to set up and it only makes sense to stop digging if prices fall below variable costs" (The Economist, 2013).

faced a short life expectancy and who faced more uncertain property rights. They were hence likely to operate with a shorter-term planning horizon. This is confirmed by narrative evidence (TePaske, 2010, pp. 32-36), and illustrated by the fact that following the discovery of a new mine most of the quantities tended to be extracted in the first few decades. While there were major mines that took decades to exhaust, in other cases "mining camps were likely to appear suddenly, to flourish briefly, and to vanish overnight" (Boxer, 1962, p.269).

Local case studies suggest that the timing of different quantities of production was dictated by local production costs, themselves a function of the available technology at a given moment, local administrative conditions, and the supply of mercury.[15] Mining production was not driven by short-term price fluctuations or economic conditions in Europe. Mines were most productive in the first few years after being discovered, unless technical progress later took place. For example, after the approximately simultaneous discovery of important Mexican and Peruvian silver mines in 1545-6, the richest veins were exploited first, following the ancient Native American technology known as the *guaira* technique. In the well-known Potosí mine, for example, technical progress existed but it was slow; and by the mid-1560s production was in clear decline following the depletion of the richest surface ores. The exploration of underground ores required more advanced technology combined with a substantial investment (Gardner, 1988, p.909). Technical and organizational change then took place; following the visit of the Viceroy Francisco de Toledo during 1570-72, the mercury amalgamation process was introduced to Potosí between 1571 and 1576 (it had been invented a few years before), together with the mita system of forced labor, to which a percentage of Native Americans had to provide. Both of these factors led to an upsurge in the productivity of mines (Figure 3); see also Bakewell (1977, p.75) and (Vilar, 2011, p.121-122).[16] However, it is important to realize that "[w]ithout the capacity to refine poor ores that amalgamation gave to Potosí, enlarging the labour force would have been of little use" (Bakewell, 1977, p.58). Hence, the factors which determined variation in annual production levels were unrelated to variation in European demand.

In sum, the historical evidence suggests that local production levels did not depend on short-term variation in the price of precious metals or the state of the European economy. New discoveries of precious metals deposits led to a usually hump-shaped production cycle pattern whereby initially the richest veins were explored, followed by diminishing returns occasionally interrupted by technological change or other factors.[17]

[15]Mercury was normally duly provided, and stocks were held to meet future demand (Bakewell, 1971, p.155).

[16]The productivity of Potosí declined later, as shown in Figure A1. For the case of Brazil see (TePaske, 2010, p.47). As a general rule, the introduction of new mining techniques that raised mining productivity could lead to exceptions to the general rule that most of the quantities were extracted in the decades following the discovery of each mine. The application to the Potosí mines of the mercury amalgamation (*patio*) process to extract silver from ore is an example of this, and one that supports the argument that the timing of the decision was not based on the state of the European economy, but instead on local conditions in America.

[17]Other factors included variation over time in access to slaves and in the integration of the different parts of the colonial economies, in particular, the farming, grazing, and mining sectors. For a review of the important case of New Granada, see TePaske (2010, pp.38-39). Occasional warfare with the natives was also a factor that generated annual variation in production levels (Bakewell, 1971, p. 27).

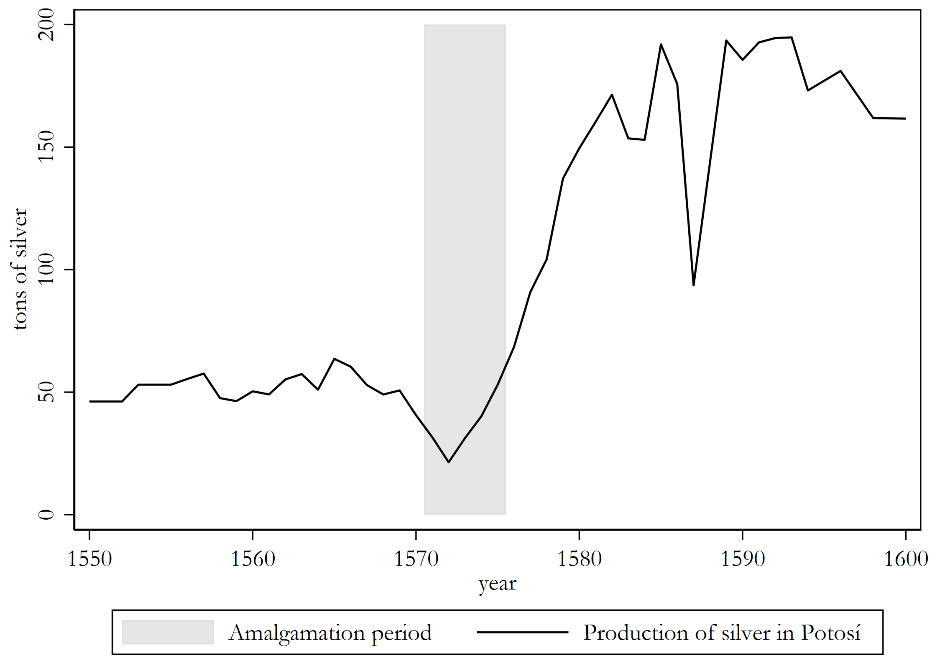

Figure 3: Potosí silver output around the time of the introduction of the amalgamation process. Source: TePaske (2010).

2.3. Data

The period covered in this study is 1531-1790, and the panel is balanced. The dependent variables are nominal GDP, the price level, and real GDP. The main independent variable is the value of precious metal production in America, as a share of the European stock.[18] Six countries are included in the panel: England, Holland, Italy, Spain, Portugal, and Germany.[19] Nominal GDP, prices, and real GDP are shown in Figures 4, 5, and 6. I discuss the sources and construction methodologies in some detail below. The starting date for my sample is determined by data availability: the precious metals output data begins systematically from 1531 (Jara, 1966; TePaske, 2010).[20] It would also not be possible to go much further back in

[18]Using coinage from mint output data for the numerator is not an option since such data would have to cover coinage in Europe as well as the Americas, leading to identification problems. Additionally, it includes reminting, leading to double-counting problems that are difficult to correct for. The existing data are also very incomplete. For example, in America several mints were used as military barracks and jails during the early nineteenth century, leading to the destruction of earlier records: "For the first 150 years of the casa de moneda in Mexico, reliable data on coinage are simply not available" (TePaske, 2010, p. 229, 247). Partial data on arrivals to Europe is available, but in addition to being endogenous to conditions in Europe, imported quantities are not always avaliable at the annual level plus there is much controversy about the precise quantities and timings, in part due to an additional layer of smuggling and tax-avoidance (Costa et al., 2013; Gonzalez, 1996; Hamilton, 1934; Morineau, 2009). All things considered, annual American production is the best option for an exogenous source of variation for money in Europe, even if not all of that production arrived to Europe.

[19]I follow the convention of using modern borders even though some of these countries did not yet exist politically as such. Additionally, in the case of Italy the available data corresponds to north and central Italy only.

[20]The underlying source is fiscal: tax records kept by the colonial treasury offices (Elliott, 2006, p.139). They are certainly not perfect. The ledgers did not always follow a January-December calendar (this has been corrected when possible), and missing documents can lead to partial gaps in some of the underlying regional series (I used interpolations when needed). I was guided by the principle that I am here estimating a lower bound to the true

time because earlier there would be little variation in the annual production levels for precious metals in the Americas.[21] Most silver and gold arrived in Europe already minted, and I observe production at the moment taxes were paid, which was often also when coins were minted; they would then be ready to be shipped overseas at short notice. As for the final date, 1790, it is determined by two considerations. First, coin became relatively less important as a percentage of the money supply of some European countries around that time, initially in England, but then also progressively elsewhere (O'Brien and Palma, 2020). Second, after the late eighteenth century, the start of modern economic growth in some of the countries in the sample would lead to nonstationarity in the GDP series (even after the inclusion of linear and quadratic trends) and confounding problems. My main specification uses a log transformation of the dependent variables and controls for linear and quadratic trends, which make the data stationary, as shown in Figures A2 to A4 of the Appendix.[22]

I use the 1531-1700 period for the baseline estimates, because gold becomes a large share of total production during the eighteenth century, as Figure 7 shows. The importance of gold during the eighteenth century leads to increased attenuation bias, because I have annual estimates only for production of silver, while I have annualized the gold data from data which is only available at 10-year intervals.[23] My results still hold if the full sample until 1790 is used, but the magnitude of the effect becomes smaller, as one would expect from the bias of the coefficients towards zero under the assumption of an additive measurement error. Overall, my dataset is considerably larger than the datasets typically used in the empirical macroeconomics literature that aims to identify the effect of monetary shocks. The construction of such an extended dataset was made possible by the fact that, in the last decade, economic historians have reconstructed GDP at the annual level for several premodern economies. Since the availability of annual GDP data for this period may seem surprising, I discuss below how this data has been constructed. I provide only a summary in the main text, but give more details in the Appendix.

Construction of the causal variable. As mentioned, the causal variable is the American production of precious metals in a given year as a share of the European stock of precious

quantities mined, because of incomplete records and fraud. There were several monitoring mechanisms against tax evasion in place, however, and severe penalties for those caught, including death (Hamilton, 1934, p.17). Smuggling rates are sometimes observable in the case of shipwrecks and estimated to be about 20% of the total values (Marx, 1987, p.26).

[21] The book by (TePaske, 2010) has the most complete quantification of the annual output of the production of gold and silver in the Americas, and it is the main source that I rely on for the construction of my series. As it was left unfinished at the time of the author's death, for some cases the totals given in the book do not precisely match the summation of annual outputs even within each region given in the book. I have corrected this as best as I could, assuming that the output for individual treasuries is the most updated data while cross-checking with alternative sources such as (Vilar, 2011). Additionally, TePaske (2010) only gives annual data from 1559 for Mexico and 1545 for Peru. Hence, for the silver in the latter region I rely on (Jara, 1963, 1966) for 1531-1544, who does give annual production, albeit only for a small number of treasuries. The latter sources in fact goes beyond production in the conventional sense of quantities mined as it includes looted treasure which took the form of non-monetary metals that had been gathered by the natives prior to the Conquest.

[22] Another reason to stop in 1790 is that the French revolutionary and Napoleonic wars combined with the rise of paper money led to inflationary experiences with fiscal origins in several countries during the 1790s, events which were not directly related to the production of precious metals in American mines (Sargent and Velde, 1995).

[23] An additional reason is that smuggling with the purpose of tax avoidance was higher in the case of gold, given that its lower physical volume per value made it is easier to hide (Boxer, 1962, pp. 200-1).

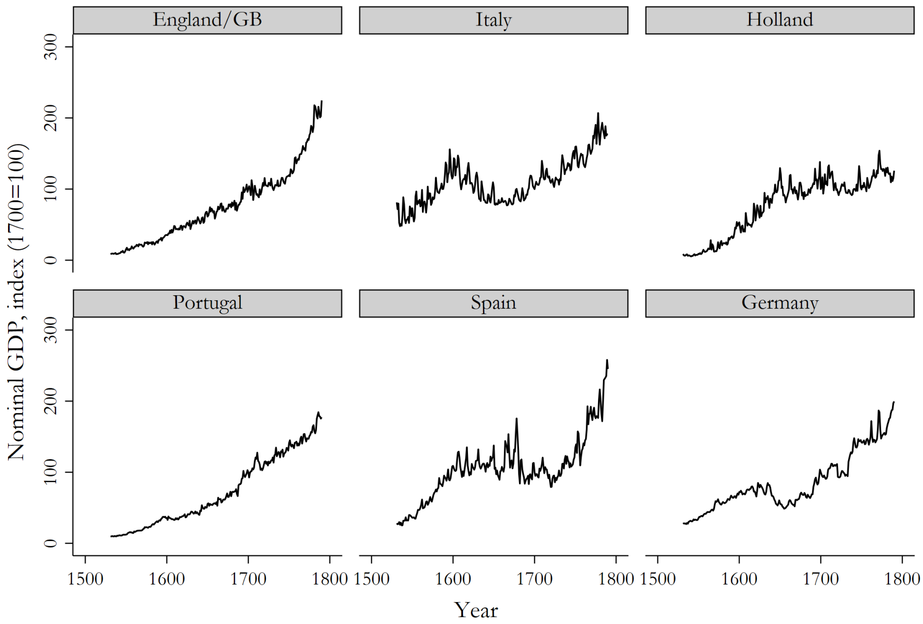

Figure 4: Nominal GDP. Sources: see text.

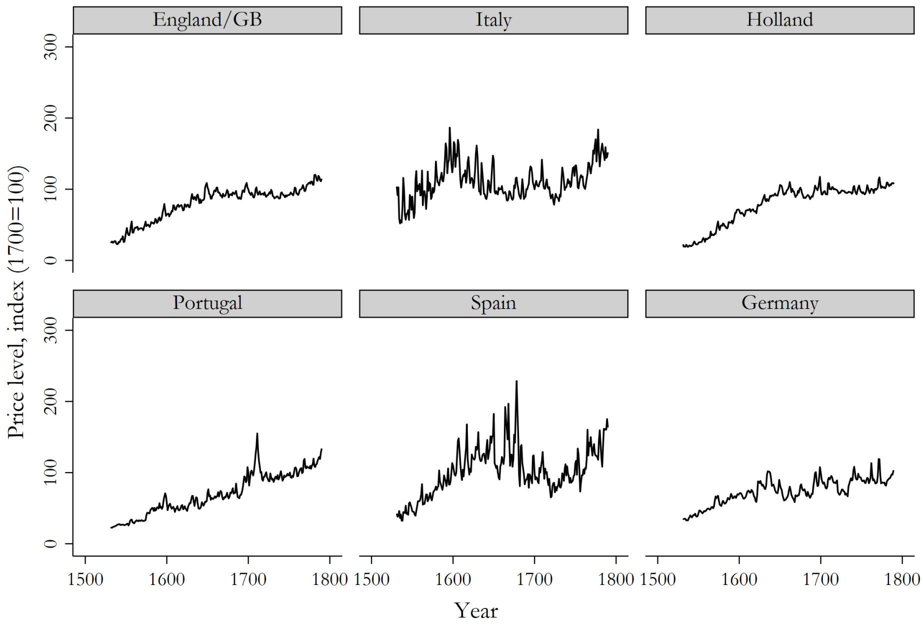

Figure 5: Price level. Sources: see text.

metals.[24] In the case of silver production, all data corresponds to the annual value of production,

[24]I subtract the silver that was lost in shipwrecks that occurred in the Atlantic using the dataset from Brzezinski et al. (2019). I assume that the silver was lost one year after production, whereby I also add any salvaged silver back in that year. The shipwrecks are limited to Atlantic losses, and I exclude silver lost in maritime disasters that happened in the context of piracy or naval combat, which could be endogenous (and because most of such silver lost by Spain in this context found its way to Western Europe anyway).

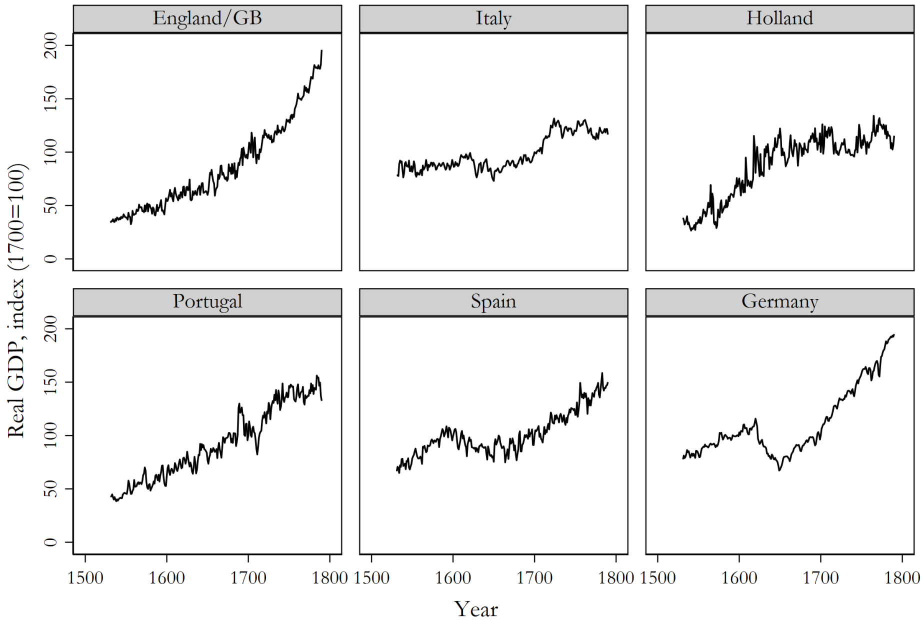

Figure 6: Real GDP. Sources: see text.

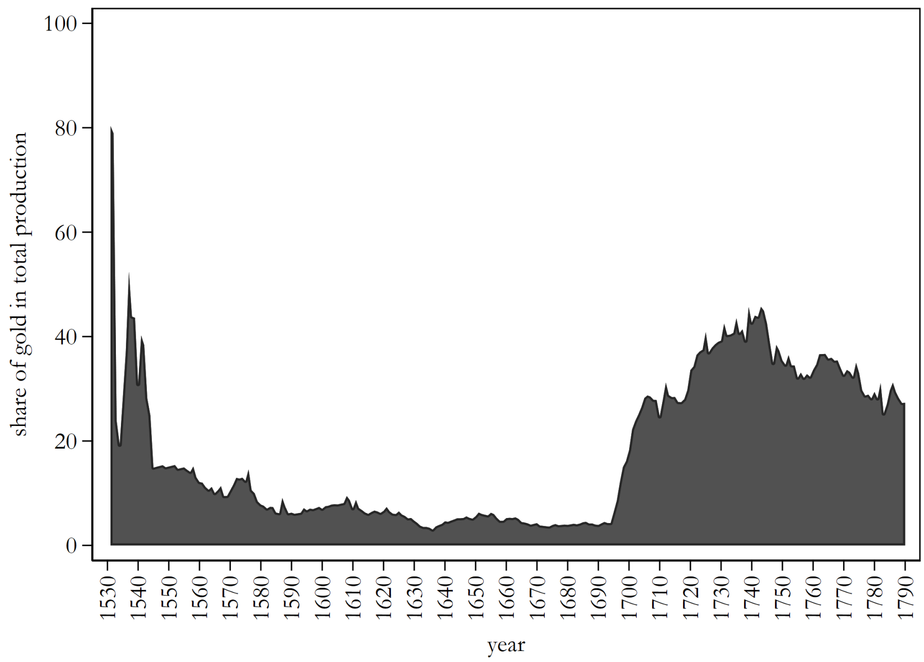

Figure 7: Relative amounts of gold production and silver production. Sources: TePaske (2010) and Jara (1966).

with the exception of a few short periods for some treasuries for which I am forced to use interpolations or the annualized values of averages due to lack of annual data (this corresponds to some loss of high-frequency variation in the independent variable, leading to attenuation bias). The sources are TePaske (2010) and Jara (1966). To the best of my knowledge, unlike in the case of silver no annual production figures for gold exist except for a small number of treasuries in sixteenth century Peru. I hence use ten-year averages taken from TePaske's compilation of sources. I translated gold kilograms to silver using their relative price (Barret, 1990, p. 238).

I have built the European stock of precious metals as follows. I start with the 1492 world stock given by Velde and Weber (2000, p.1230). I then calculate the European share using both per capita incomes and population from the most recent Maddison Project dataset (Bolt et al 2018).[25] This procedure leads to the initial European stock. I then add annually the new world production while subtracting exports to Asia as well as what was lost at sea or stayed in the Americas.[26] I also apply an annual 1% depreciation rate, as is commonly done in money stock estimation studies.[27] European production is assumed to have been zero, which is a good approximation historically (see Figure A5 in the Appendix).[28] The resulting measure is shown in Figure 8, which corresponds to the causal variable of interest. Note the initial peak: it is correct, since production of precious metals in the Americas increased dramatically from the 1540s, and hence so did its value relative to the European stock. As Hamilton (1934, p.vii) wrote, "No other period in history has witnessed so great a proportional increase in the production of the precious metals as occurred in the wake of the Mexican and Peruvian conquests". However, once the European stock rose over time, the annual production of precious metals became smaller relative to the denominator from the late sixteenth century. It would again increase in the 1700s with the new inflows of Brazilian and Mexican production, generating a second peak around the mid-eighteenth century. The sudden downward peaks in the figure are due to shipwrecks.

Outcome variables. I now briefly describe how premodern GDPs (and prices) have been built in the historical national accounts literature.[29] Annual prices have been collected from surviving account books which exist in national and regional archives (Palma, 2020). Two GDP reconstruction methods have been used. The most accurate, but also more demanding in terms of underlying data, is the supply-side approach which has been used to reconstruct the GDP of England (Broadberry et al., 2015a) and Holland (van Zanden and van Leeuwen, 2012). For these countries, it is possible to calculate the different yearly components of output at current prices, which are then aggregated and transformed into real values by using a price index. For instance, Broadberry et al. (2015a) use, for agriculture, yearly data on agricultural land output, taking into account crop and livestock production. For industrial production, they aggregate the output of industries such as tin, coal, textiles, and wool. For services (broken down into government services, commercial and financial services, and domestic and personal services), they use individual series when available and proxies when not. Hence, for both agriculture and

[25]In the case of the baseline European initial stock, it is calculated as 23% of the Velde-Weber figure, using the European share of global output in PPPs from the Maddison Project; see Brzezinski et al. (2019) and Palma (2019) for details.

[26]As with the flows, I convert gold values into silver by using the bimetallic ratio from Barret (1990, p. 238).

[27]See Brzezinski et al. (2019, p.4) for details about the procedure. Velde and Weber (2000) use the same depreciation rate for the period prior to their end date of 1492; this rate capures not only physical depreciation but also coins lost in daily usage.

[28]My procedure has a similar trend to the only other attempt I know of to build this stock, Morineau (2009, p.581-3), who gives an estimate at 10-year intervals.

[29]For further details, see the Appendix.

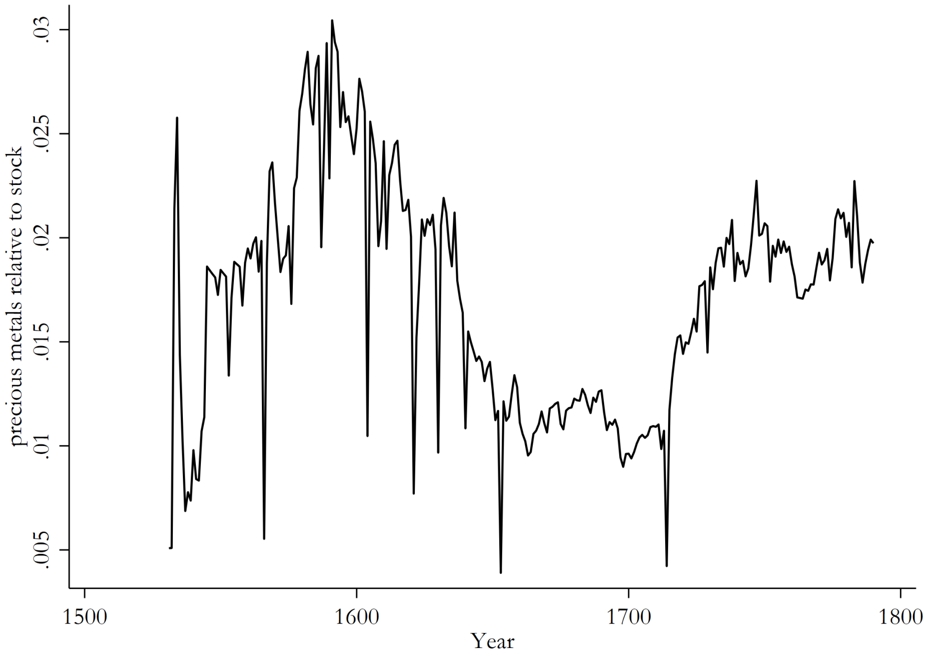

Figure 8: Production of precious metals in America measured relative to the stock of metals in Europe. The series is adjusted for losses of metals caused by shipwrecks (leading to the visible downward peaks), using data from Brzezinski et al. (2019). Sources: see text.

industry (and to a lesser degree services), prices and quantities are observed directly for every year.

For countries with less available data, the alternative is a more indirect, consumption/demand-based method. The countries for which such estimates now exist, going back to the sixteenth century or before, include Italy, Germany, Spain, and Portugal.[30] This method first produces an estimate for agricultural income, using real wages (Deaton and Muellbauer, 1980; Wrigley, 2014). Agricultural GDP is calculated in this standard way across these studies; then three alternative methods have been used to estimate the other sectors of each of these economies, finally leading to GDP (see the Appendix for details). Several studies have confirmed that output and demand-based GDP reconstructions tend to be consistent with each other.[31]

[30] Álvarez-Nogal and Prados de la Escosura (2013, 2017); Malanima (2011); Palma and Reis (2019); Pfister (2020). In the case of Portugal, the method also uses some output-level data, technically making the resulting series a hybrid of demand and supply methods. In the case of Spain, a more recent estimate of agricultural output from the supply side has confirmed the overall pattern of the demand-based estimates (Álvarez-Nogal et al., 2016). Finally, for Germany I have relied on the unpublished GDP data of (Pfister, 2020), but the results are similar if instead I use real wages multiplied by population as proxy for GDP (Pfister, 2017).

[31] For example, Palma and Reis (2019, p.498) show that these alternative methods lead to similar results for the case of Portugal. See also Broadberry et al. (2015a, pp.120-124), Broadberry et al. (2015b, p.65), Álvarez-Nogal et al. (2016).

3. Empirical implementation and identification strategy

The main contribution of this paper is to use a novel source of exogenous variation in European money supply: the production of precious metals in the Americas. As previously mentioned, in order to take into account the rising amount of precious metals available to Europe, I define the shock as the production of precious metals in America measured relative to Europe's stock. Since the shock is common to every country, the identification is not coming from different cross-sectional exposure, but from time-variation in the shock. Given that these were integrated economies, the shocks will have affected them all, even if possibly with different timings.[32]

Starting with panel data results, I estimate independently separate equations for nominal GDP, the price level, and real GDP, using the Jordà (2005) local projections method. As long as variation in the independent variable was indeed exogenous, the estimated parameters identify reduced-form causal effects, hence an explicit system of equations is not required.[33] I then show country-specific estimates, followed by an IV strategy that specifically looks at the mechanism running from production of metals to mint output and then to GDP. I argue that the main mechanism at operation is a liquidity effect (rather than a wealth effect), and I test this using money supply data for England, the only country for which such data is available at annual level for the baseline period which I consider.

3.1. Baseline results for a panel of European countries

My econometric specification follows Jordà (2005)'s local projection methodology. For each time horizon h, I estimate the following equation:

$$\ln(y_{i,t+h}) - \ln(y_{i,t-1}) = \alpha_{i,h} + \beta_h \ln(s_t) + \boldsymbol{\psi_h} \mathbf{x_{i,t}} + u_{i,t+h} \tag{1}$$

The outcome variable is the difference between the natural logarithm of y at time period $t+h$ less its value at period $t-1$, where y is alternatively defined as nominal GDP, the price level, or real GDP. The main independent variable is s_t, the production of precious metals in America measured relative to the stock of metals in Europe. The vector $\mathbf{x_{i,t}}$ comprises country-specific controls, including linear and quadratic trends, weather controls[34], an indicator on whether a country is at war with Spain (Clodfelter, 2008)[35], as well as lags of these control variables and

[32] Exactly how integrated these economies were depends on the exact definition and metric used to measure integration (Federico, 2011). They were not as integrated as today (especially the labor markets but also with respect to bulk trade) but all of these economies traded with each other.

[33] Since the shocks are structural they will not, up to a random error (asymptotically), be correlated with other variables that influence output.

[34] I use air temperature, based on Anderson et al. (2017)'s treatment of the Guiot and Corona (2010) dataset. I chose the temperature at the capital city of each of the countries in my database. In the case of Germany and Italy, which did not yet exist as modern political entities, I use Berlin and Genoa; the choice of the latter is justified by the previously noted fact that Malanima (2011)'s GDP for Italy is based on data for north and central Italy only.

[35] I classified England as not at war with Spain during 1630-48 (Cottington treaty) and the Dutch Republic

of $\ln(y_{i,t})$.[36] $\alpha_{i,h}$ are horizon and country-specific fixed effects, while $u_{i,t+h}$ is a horizon-specific error term.

The local projection method proceeds by estimating a separate regression for each horizon h. I consider a 12-year window, such that h runs from 0 to 12, but the results also hold for longer horizons.[37] The coefficients of interest are β_h for each horizon h. These capture the impact between $t+h$ and $t-1$ on the dependent variable of a 1% increase in the production of precious metals (relative to the stock of metals in Europe). Hence, β_0 shows the initial impact of precious metals on the growth in the dependent variable, $\ln(y_{i,t}) - \ln(y_{i,t-1})$; β_1 shows the impact on the growth between periods $t+1$ and $t-1$, $\ln(y_{i,t+1}) - \ln(y_{i,t-1})$; and so on.

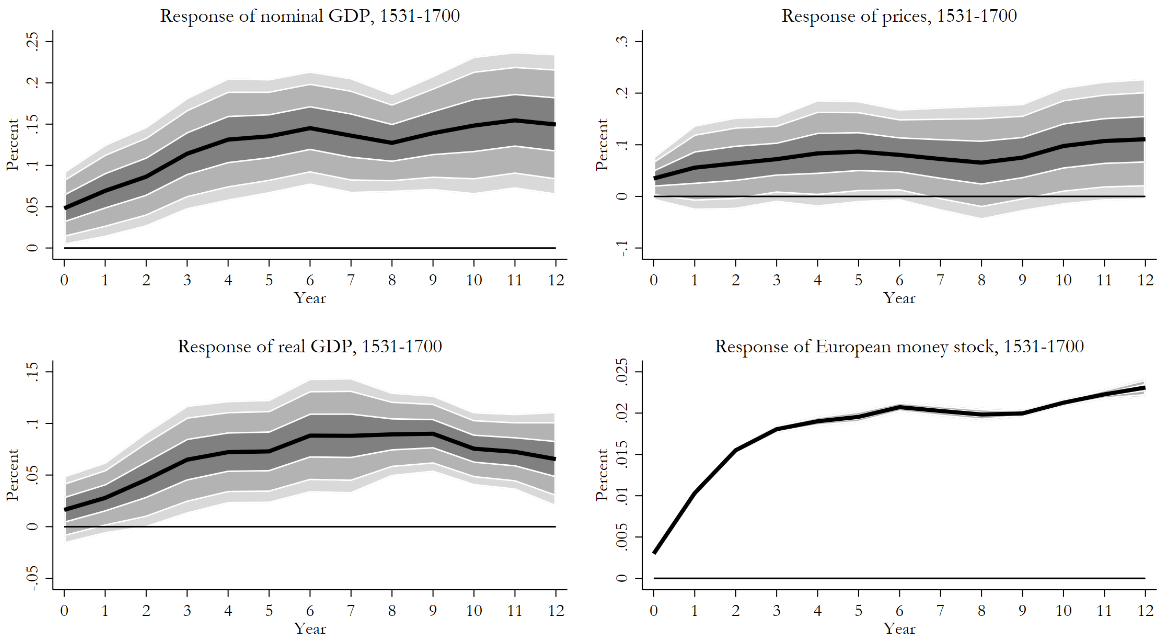

Figure 9: Impulse response of nominal GDP, the price level, and real GDP to a contemporaneous 1% increase in precious metals relative to stock (1531-1700), calculated using the Jordà (2005) local projection method. Country fixed effects are included, and standard errors are clustered by country to control for correlation in the error term across years. One standard deviation, 90% and 95% confidence intervals are shown. The regressions control for four lags of the dependent variable, country-specific linear and quadratic trends, contemporaneous and four lags of temperature, and a dummy variable indicating whether a country is at war with Spain in a given year. For robustness checks with different lag lengths and control variables, see Appendix Figures A8-A15. Sources: see text.

Figure 9 shows the estimated impulse response function for real GDP, nominal GDP and the deflator, alongside 1 s.d., 90% and 95% confidence intervals, for the baseline period 1531-1700.[38]

as at war with Spain during the Eighty Years' War (Dutch War of Independence, 1568–1648). In any case, my results are robust to alternative classifications in this variable.

[36]The exact set of variables and lags included in each specification is indicated below each figure. Notice that the criticism of Nickell (1981) only applies to short panels (the inconsistency is of order $1/T$, so when T is large, as is the case here, there is no need to use a dynamic panel).

[37]However, the exact effects on real GDP become harder to identify precisely due to the tendency of confidence intervals to grow for longer horizons. For a horizon of 20, see Figure A6 in the Appendix.

[38]Standard errors are robust and clustered by country to control for within-country correlation in the error term across time. Note that I adopt a conservative approach by allowing arbitrary correlations in the error term,

Nominal GDP is affected by an increase in precious metals on impact, and the overall effect of the monetary shock is increasing at a decreasing rate over time. On the other hand, the price level response is weaker. Note that the point-estimate response of nominal GDP exceeds that of the price level in each time period. This explains the positive and significant response of real GDP, as also shown in Figure 9. The growth of real GDP is gradual, and has a peak effect around years six to nine: A 10% increase in precious metals production relative to their stock at time t leads to an increase in real GDP of approximately 0.9% by year $t+9$. After this peak, the (point estimate) effect of the monetary shock on real GDP diminishes, as the price level rise increases in intensity.

The fourth (lower-right) panel in Figure 9 shows that the European money stock increases by between 0.01% and 0.02% to a 1% increase in the shock variable (precious metals production relative to the stock) over a horizon of 1-10 years. Note that the annual production of precious metals usually corresponds to about 1.5% of the European stock, as shown in Figure 8. Thus, it is intuitive that a 1% increase in the shock variable translates into approximately a $1\% * 1.5\% = 0.015\%$ increase in the European money stock.[39]

Neither the selection of control variables (including adding lags of the shock) nor the choice of lag lengths for the dependent variable drive the qualitative results (see Figures A8-A15 in the Appendix). In this and the following two paragraphs, I refer to additional results which consider alternatives to the baseline sample. Figure A16 in the Appendix shows the main results when using the entire period 1531-1790. As discussed above, the data for gold production in the eighteenth century is only available at 10-year intervals, so the inclusion of the eighteenth century leads to attenuation bias, as gold then gains a much larger share of the total value of production of precious metals. As expected, the response of real GDP is smaller when incorporating the entire period into the analysis. Nevertheless, the results remain qualitatively similar: The response of nominal GDP initially exceeds the response of the price level, while real GDP has a similar hump-shaped response, albeit of smaller magnitude.

Another possibility is to express nominal GDP and prices in silver rather than monetary units, controlling for changes in the silver content of the unit of account of individual countries.[40] While some of the rise in prices over the early modern period can be explained by debasements, I do not to control for this in the baseline specification due to the possibility that such changes

instead of using a HAC-based adjustment. Often, macro empirical papers do not show 95% confidence intervals; in this too I have been more conservative. Additionally, my results are similar when using a two-way cluster specification, as I show in Figure A7 in the Appendix.

[39] The baseline results can therefore be understood relative to an increase in the European stock: after 6 years, for example, a 10% increase in the precious metals relative to the money stock corresponds to an exogenous 0.21% increase in the European stock, which increases real GDP by around 0.9%. Notice, however, that this is the stock that applies to Europe as a whole, hence the percentage increase in the money stock in this sample of six countries, which include Spain and Portugal, would be larger than 0.21%.

[40] For this I rely on the Karaman et al. (2019) dataset, with two exceptions. German currencies are not included, so I rely on Allen (2001)'s series for Leipzig, who in turn relies on Elsas (1940). For Italy I rely on Malanima (2002, p.409)'s series for Florence, which has a closer correspondence to the sources used by Malanima (2011) to reconstruct GDP than the series for Venice used by Karaman et al. (2019). In some cases the authors of the national income series already provided their price indexes in silver units. For these cases I conducted the reverse operation in order to recover the price indexes in monetary units which I use in the baseline analysis.

were endogenous to the arrival of precious metals from America. In the appendix, Figure A17 shows the results until 1700, and Figure A18 until 1790. The results are similar to the baseline results, which suggests that there was no systematic endogenous response of debasements to the arrival of metals, confirming a similar argument made by Brzezinski et al. (2019).

In a final alternative, I do not adjust the production of metals in the Americas to shipwrecks of the silver fleets that occurred in the Atlantic. The results, shown in Figure A19 and Figure A20 of the Appendix, are qualitatively similar to the baseline results. The results also remain similar when shipwrecks-adjustments are made in alternative ways (see Figures A21-A24 in the Appendix).

3.2. Was there a heterogeneous response for different countries?

I have so far maintained that the annual production of precious metals in America was exogenous to the state of the European economy as a whole, an assumption which I defend in detail in section 4. This assumption is compatible with the possibilities that once extracted, different amounts went to different countries (McCloskey and Zecher, 1976), and had heterogeneous effects. To test for heterogeneity of responses across countries, I run a series of country-specific regressions using the following specificiation for each country:

$$\ln(y_{t+h}) - \ln(y_{t-1}) = \alpha_h^c + \beta_h^c \ln(s_t) + \boldsymbol{\psi_h^c} \mathbf{x_t} + u_{t+h}^c, \tag{2}$$

where, as before, the left-hand side is the log-change in the outcome variable of interest across horizon h; α_h^c is a horizon-specific constant term; s_t is the shock variable; $\mathbf{x_t}$ is a vector of control variables whose components are described below each local projection figure; and u_{t+h}^c is a horizon-specific error term.

The results are shown in Figure 10.[41] For two countries, Spain and Portugal, the effects on real GDP are particularly pronounced from an earlier date, around years 0-4. This is likely to be due to the more immediate (and less variable over time) passage of metals from production to Spanish or Portuguese coin circulation, the money being ready to use for trading with other European countries, and some wealth effects.[42] Only after arriving to Spain did the money move to other countries via trade networks and military payments. Hence, in Spain (and nearby Portugal), the time lag between the arrival of metals and the minting of new coins was less variable over time. In contrast, the lag between the production of metals in America and the

[41] I use Newey-West standard errors which allow for serial correlation in the error term of up to one lag (two lags leads to similar results). Wooldridge (2009, p. 429) recommends one or two lags for annual data.

[42] Precious metals were produced, and for the most part minted into coins in America, after which they arrived in Spain. The vast majority of the coins minted in Spanish colonial mints "left Spanish America immediately to go elsewhere" TePaske (2010, p.224). The results for Italy are also strong, which may be attributable to the fact that for long periods of the sample, Italian merchants and bankers were involved with business and financing to Spain, and parts of Italy were under the rule of the Spanish Crown, requiring frequent military and diplomatic payments.

arrival of these metals in the other countries of the sample was more variable, due to disruptions in the trade networks with Spain. For all countries, the results are significant around years 6-9 under the baseline specification for the shock that takes shipwrecks into account.[43]

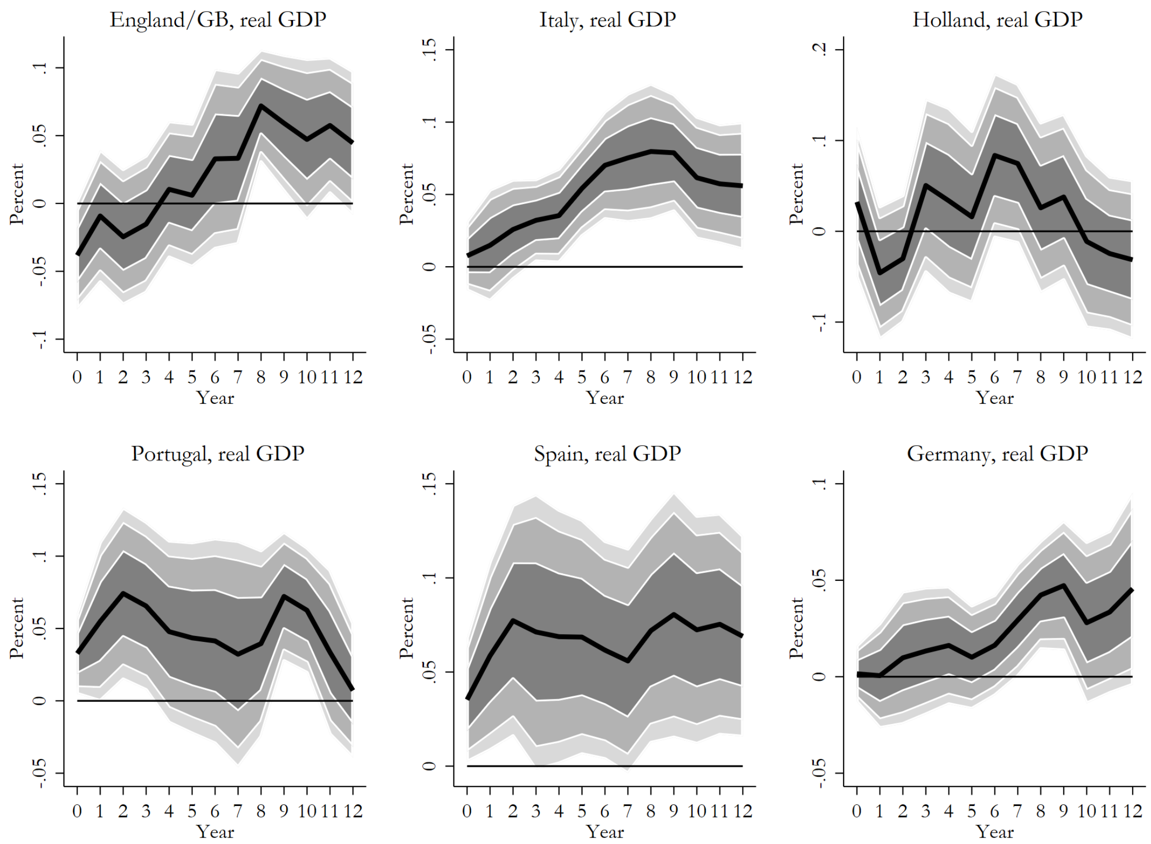

Figure 10: Local projections for response of real GDP to a 1% increase in precious metals relative to stock (1531-1700), by country. Each graph shows a separate set of time series local projections for each country. Newey-West standard errors are employed to control for autocorrelation in the error term. One standard deviation, 90% and 95% confidence intervals are shown. The regressions control for country-specific linear and quadratic trends, four lags of the dependent variable, contemporaneous and four lags of temperature as well as a war with Spain dummy.

3.3. American precious metals and European mint output

In the previous subsections I have shown reduced-form results of the impact of American precious metal production on the European economy. The results are reduced-form in the sense that the structural transmission mechanism of the monetary non-neutrality effect runs from metal production in America to national mint outputs in Europe in a first stage, and then from mint output to real GDP and prices in a second stage. I now examine the association between precious

[43] In the case of Holland, the result is only significant at 10%, while for the other countries it is significant at 5%. When not controlling for shipwrecks, the results remain similar, but the effects for Holland and Germany are not significant; see Figure A25 in the Appendix. The results are also similar when adjusting for shipwrecks in the same year as metals production takes place (Figure A26) or if losses due to combat and piracy are also deducted from the production of precious metals (Figure A27).

metals, mint output, and the outcome variables in more detail. Together with the case-study of Spain (in the Appendix), the evidence I provide here supports the view that the results were not mainly due to wealth effects.[44]

National mint outputs provide evidence that the arrival of precious metals from America increased European money supplies. The spread of Spanish-origin coin through Europe is not directly observable because countries melted foreign specie into their national currencies.[45] National mint output data does exist in fragmentary form for a few European countries, however. Besides that of England, the best quality (based on the number of years for which data has survived) corresponds to Holland, France, and Genoa which I show in Figure 11.[46] In the figure, zeros are typically missing observations, rather than actual zeros. I adjust for the silver value of each monetary unit so that nominal mint output measures how much silver was being minted annually, rather than simply how many monetary units were being issued (Karaman et al., 2019).[47] As the figure suggests, there is a close "first-stage" association between mint output and production of precious metals (in silver-equivalent tones) in the Americas. While mint output was flat for both countries until about 1700, it increased afterward, in accordance with the increase in New World metals production.[48] This overall minting pattern is also consistent with the even more fragmentary mint output evidence available for Castile (Motomura, 1997, p.355), and Portugal (Sousa, 2006, p.263-73).[49]

In the case of England, both mint output and coin supply are available. Figure 12 shows English nominal mint output during the 1531-1790 period. Mint output had been rather low during the fifteenth century, but as the figure shows it increased from the sixteenth century onwards, becoming "entirely unprecedented" in the words of Mayhew (1999, p.57). This is suggestive evidence that the increases in American precious metals did lead to increases in money supply in Europe, including for second-wave receivers such as England which received it mainly by trading with Spain and Portugal.[50]

[44]England received its share of the silver and gold via trade and diplomatic transfers, rather than directly. But even for Spain, the value of the silver and gold was not of sufficient value to have large wealth effects; in Appendix D I show that Spanish annual precious metal inflows ranged only between 0.04% and 0.4% of the Spanish wealth level.

[45]Nonetheless, hoards of Spanish coins have appeared in several countries such as France and Denmark (Moesgaard, 2012).

[46]I start in 1640 because the data for Holland is fragmentary before that date. Additionally, French data only covers some of the mints; see also Velde (2009, p.602).

[47]Despite this adjustment, exceptionally high years typically correspond to debasement years. This was the case for instance with France in 1718, which corresponds to the peak visible in the graph when the grams of silver required to mint one monetary one *livre tournois* were decreased by about a third (Karaman et al., 2019). Since old coin would have been melted, the peak does not correspond to a net change.

[48]Indeed, French coins during the eighteenth century contain much Brazilian gold (Barrandon et al., 1999).

[49]In addition to being fragmentary, mint output data for the later two and their American empires is not representative of normal Western European levels due to the fact that these were the producers of the metals.

[50]The chemical composition of English coins confirm the Spanish-American origin of much of English silver coinage (Desaulty and Albarede, 2013). Scientists have hence confirmed the view of historians who claimed that "there can be no doubt that Spanish bullion did come into the mint, and did so in such quantity that ... [at times] it formed the core of mint supply" (Challis, 1978, p.195); see also Mayhew (1999, p.63). The scientists have traced the provenance of coinage through variations in their isotopic abundances, which is possible because European silver can be distinguished from Mexican and Andean metal. They conclude that "Nine out of the 12 [English] silver coins from the 16th to the 17th centuries were minted from 50-90% bullion from Mexico, or from foreign denominations that contained Mexican silver [...] If geologically old English lead was used during

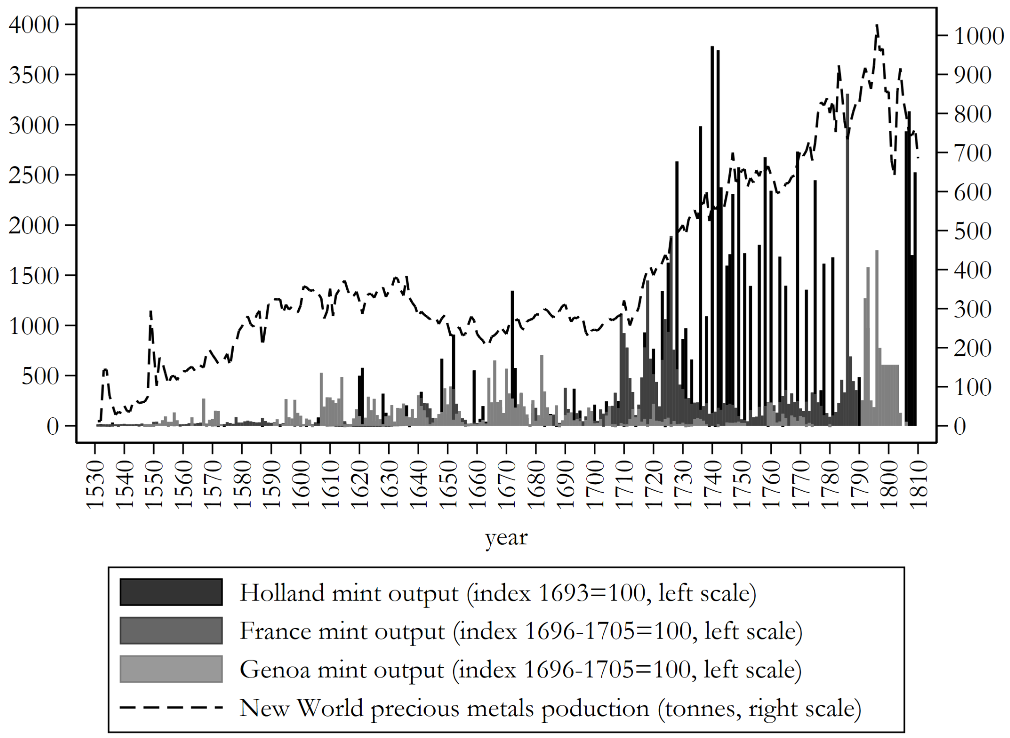

Figure 11: New world precious production (in silver-equivalent tonnes) and nominal mint output in Holland, France, and Genoa in country-specific units of accounted indexed to 1696-1705. Zeros in the graph typically refer to missing data. Sources: Spooner (1972, pp.334-341), Morineau (1984), Stampel (2016), Zuijderduijn et al. (2018); Felloni (1976, p.318-23); Jara (1966); TePaske (2010).

3.4. IV estimation for England

Changes in precious metal production in America can be used as an IV for changes in England's money supply, in turn showing how the latter affected income and prices. I divide the annual mint output for England, taken from Challis (1992), by the coin stock, from Palma (2018a,b). This generates a variable, which approximately represents annual changes in the money supply.[51] Figure 13 illustrates the first-stage: annual production of American precious metals (as a share of Europe's stock) works well as an instrument for English mint output (as a share of England's coin supply).[52] As most of the money supply was composed of coins, a 1% change in the latter

reminting [...] these proportions represent a lower limit" (Desaulty and Albarede, 2013, p.136). Other studies have led to similar conclusions regarding the importance of new American precious metals for the changes in coinage of other European countries. See Barrandon et al. (1999) and Desaulty et al. (2011, p.906).

[51]Mint output is not perfect, because it is a gross measure and it underestimates annual increases when foreign coins entered circulation. For instance, after Portugal's discovery of massive quantities of gold in Brazil, Portuguese coins frequently circulated in Cornwall and elsewhere in England in their original form, i.e. without going through the Tower mint. I correct it into a net measure by taking into account the four recoinage periods reviewed in Palma (2018a,b). Furthermore, as with the treasury ledgers, mint records do not always follow a January-December calendar (Challis, 1992, p. 313).

[52]I use as the first-stage baseline a shipwrecks-adjusted shock (with combat or piracy losses excluded). However, in this baseline I spread the shipwreck losses over five years as the Spaniards were certain to smooth each shipwreck loss over a number of years when making payments that would have reached England. As in the panel results,

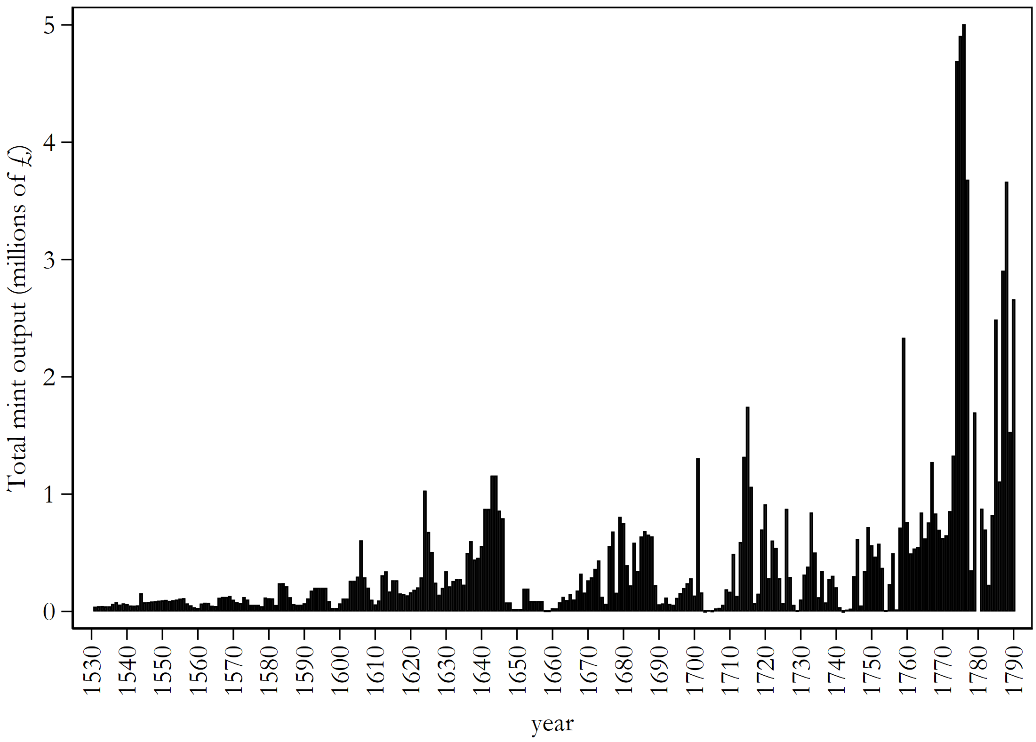

Figure 12: England's nominal mint output (in millions of pounds). Isolated peaks can correspond to recoinages, but the figure already corrects for major recoinages. Sources: Challis (1992); Palma (2018a,b).

ratio is a close proxy for a 1% change in the money supply.[53] I hence estimate:

$$\ln(y_{t+h}) - \ln(y_{t-1}) = \alpha_h^{IV} + \beta_h^{IV} \ln(\widehat{mint_t}) + \boldsymbol{\psi_h^{IV}} \mathbf{x_t} + u_{t+h}^{IV}, \tag{3}$$

where mint output as a percentage of coin supply $\widehat{mint_t}$ is instrumented by the log of American production of precious metals as a share of Europe's stock s_t; and, as before, α_h^{IV} is a constant term, $\mathbf{x_t}$ is a vector of controls, and u_{t+h}^{IV} is a horizon-specific error term.

Table 3 shows the first-stage results, which show that the instrument is relevant and the signs are as expected. For the baseline specification, I interpolate the four recoinage periods using a five-year average around each episode.[54] Additionally, I added a dummy for the Cottington

including the potentially endogenous combat or piracy cases leads to similar results. The same is true for not adjusting for shipwrecks at all, which could make sense because the English set up joint-stock companies to fish for Spanish shipwrecks (Murphy, 2009, p.10-11). As I show in Figure A28, not adjusting for shipwrecks leads to similar results for England.

[53]I focus on the period for which we have the best annual variation in precious metals production in the Americas, 1559-1700. The first of these dates is justified by the fact that we only have silver production in Mexico from that data, as well as to avoid confounding due to the fact that debased currency due to the Great Debasement remained in circulation until the late 1550s. The second is explained by the fact that we do not have annual production of gold, which became central for eighteenth century England coinage. Starting in 1531 would lead to similar, but less significant, results.

[54]This procedure is necessary to reduce measurement error because, as previously explained, recoinages would

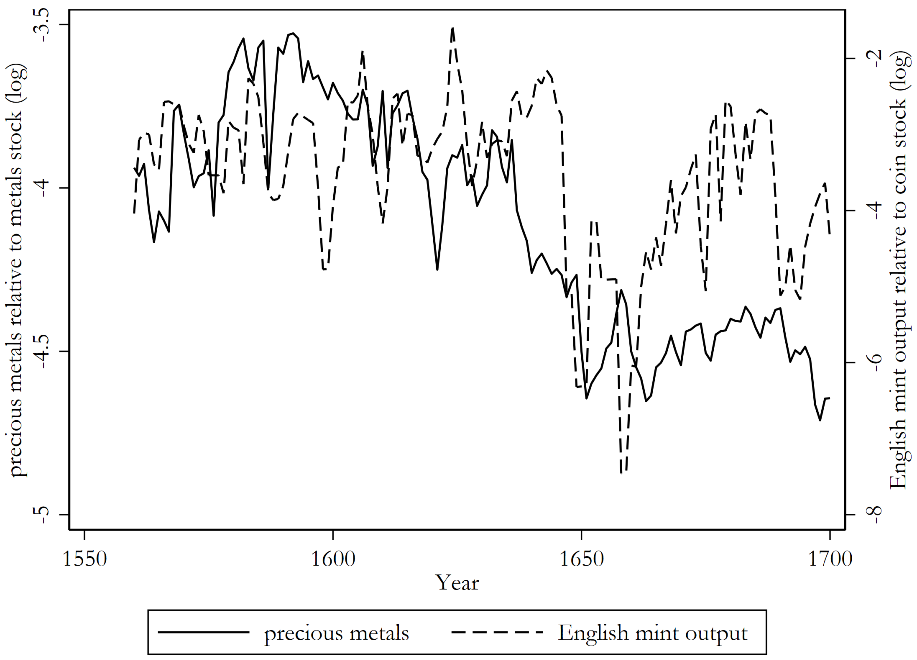

Figure 13: First-stage variables for England. Sources: see text.

treaty period (1631-1647), when England had preferential access to Spanish bullion (Palma, 2018b, p.246). For the baseline, I assume a lag of one year for mint output to respond to precious metal production, but the results are similar if either a contemporaneous response is assumed, or a lag of two years (columns 2 and 3). The fourth column shows the same specification as the baseline but without the Cottington treaty dummy. All the specifications give qualitatively similar results, and for all specifications, the first-stage F-statistic for the excluded instrument lies above the value of 10, which is usually used to assess instrument relevance. The first stage shows that an increase in precious metals increased mint output: the coefficients showing the effect of precious metals on mint output are always positive and highly significant with $p < 0.01$. According to the baseline estimate in column 1, a 1% increase in the production of precious metals relative to the European stock led to a 1.6% increase in English mint output relative to stock one year later.

The second-stage results can be seen in Figure 14. Overall, the results are qualitatively similar to the main results in section 3.1: While nominal GDP responds after 5-6 years, prices are sticky and respond less as well as later. Together, this explains the hump-shape of real GDP, which parallels the main panel results: after 8-9 years, an exogenous 10% increase in coin supply leads to a 1% increase in real GDP.[55] Hence, the results for England suggest that it is

otherwise create spurious peaks. Following the well-known Tudor debasements and recoinages of 1545-1551, there were several episodes that fall into my sample period: 1561-62 (Elizabeth's recoinage), 1662-63 (Royalist recoinage), and 1695-8 (Great Recoinage).

[55]The fact that prices do not respond 1-to-1 to monetary changes even after 12 years is related to the fact that a 1% increase in the shock variable does not correspond to the equivalent increase in the (unknown) money stock for the present sample of countries. Furthermore, changes in real output and velocity can drive a substantial wedge between money and prices. European economies were open and exported some of their precious metals and

Dependent variable: money stock	(1) Baseline	(2) Lag 0	(3) Lag 2	(4) No Cott.	(5) 3-y average
metals production relative to stock	1.628***	1.946***	1.533***	1.604***	1.751***
	(0.443)	(0.489)	(0.485)	(0.474)	(0.454)
Cottington control	YES	YES	YES	NO	YES
Observations	142	142	142	142	142
First-stage F statistic (excluded instrument)	13.5	15.8	10.0	11.4	14.9

Table 3: First-stage results for England IV regression (1559-1700). Regressions control for linear and quadratic trends and a dummy variable for the Cottington Treaty period (1631-1647).

reasonable to assume that the reduced-form panel data results from the previous subsections capture monetary non-neutrality through the increased minting activity in European states.

4. Interpretation and threats to identification

In this section, I argue that the results so far make sense in historical context. I then turn to potential threats to the validity of this natural experiment. First, I show placebo tests for the main results. These show that variation in future precious metal production levels was not anticipated. Second, I discuss the possibility that the timing of the discovery of the mines, or the mining intensity, could have been endogenous to the state of the European economy.[56] To show that this was not the case, I follow an IV strategy: using weather shocks as a source of exogenous variation to the state of the European economy (real GDP), I show that these do not cause future changes in the production of precious metals in America. Additionally, I show that a credible measure of unanticipated arrivals of precious metals to Europe looks like white noise, hence increasing the credibility of my placebo tests by ruling out anticipation effects which would have operated through the endogenous formation of expectations.

4.1. Plausibility of empirical results

There are good reasons to believe that strong monetary non-neutrality effects could exist in pre-modern economies. Late medieval Europe was distinguished by its comparatively well-developed factor markets (van Zanden, 2009). In England, about 40% of households lived mainly on wages in 1524-5, a ratio which had been approximately constant since the thirteenth century (Dyer, 2002, p.364). This is a lower bound to the percentage of people involved with market activity, since others could be for instance farmers who owned land and sold their product to the market.

coin, hence a one-to-one effect on the aggregate price level is not to be expected. See Sargent and Surico (2011) and Teles et al. (2016) for related evidence in different contexts which also suggests that although the quantity of money is an important determinant of the price level, the relationship is rarely one-to-one.

[56] In the Appendix, I discuss problems of measurement error in the independent variable. I show that measurement error is unlikely to be large.

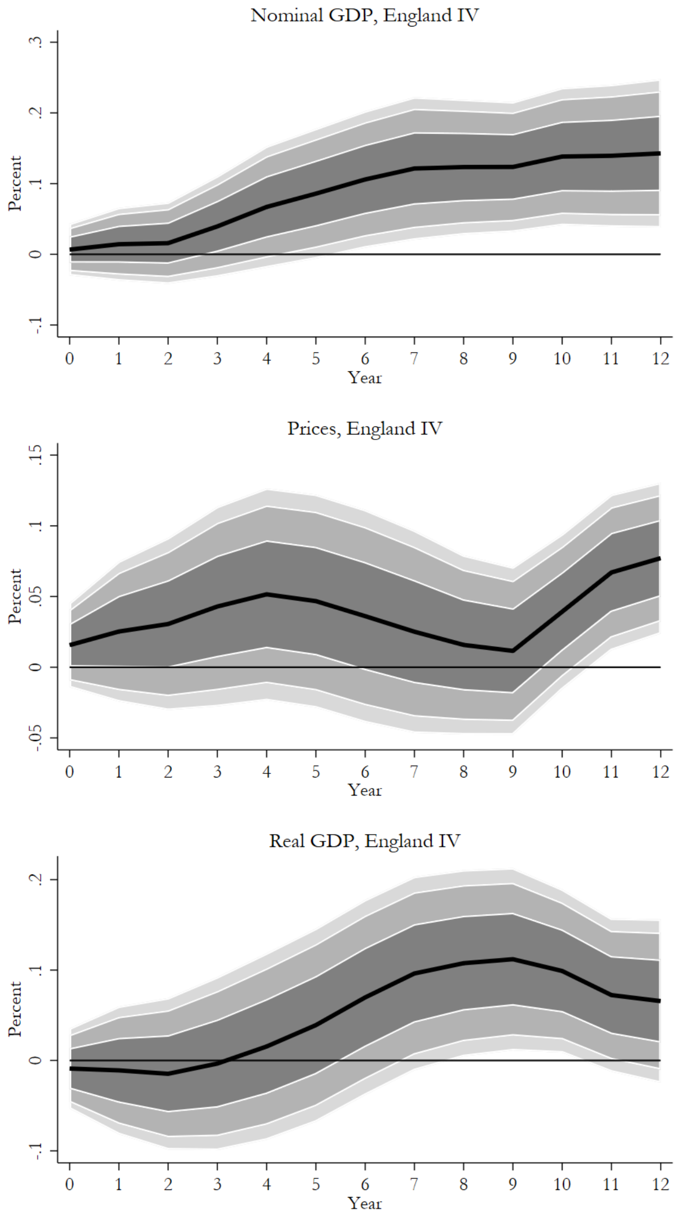

Figure 14: Impulse response of nominal GDP, the price level, and real GDP in England, to a contemporaneous 1% increase in mint output relative to coin stock (1559-1700), calculated using a two-stage IV local projection method. In the first stage, mint output relative to coin stock is instrumented by a one-period lag of production of precious metals relative to European metals stock. Newey-West standard errors are employed to account for serial correlation. One standard deviation, 90% and 95% confidence intervals are shown. The regressions control for linear and quadratic trends and a dummy variable for the Cottington Treaty. Sources: see text.

By the early 1780s, few people had no involvement in the cash economy (Porter, 1990, p.187). Money mattered not only for industry and services but also for the agricultural sector: workers in this sector used money both as purchasers of goods and services and as sellers and payers of taxes (Dyer, 2002).

The evidence from the previous sections suggests that prices were sticky in the past, as they are today.[57] Intuitively, this might not be surprising as many of the contemporary causes of price stickiness, such as menu and information costs, must have also played a role earlier in history. Additionally, social norms about when it is acceptable to raise prices and reluctance by firms to antagonize or inconvenience their customers (Blinder et al., 1998) could have operated centuries ago as well. This could be, of course, due to expectations of repeated business among people who knew each other, which in the context of small communities was even more prevalent than it is today. There is also considerable evidence of nominal rigidity in poor countries today (Kaur, 2019).

It is possible that money mattered more for industry and services than it did for agriculture, but even if that was the case, recent work by economic historians has shown that the share of non-agricultural GDP in premodern European economies was not as small as previously believed, so there was plenty of scope for money to matter.[58] Early modern Western European economies were richer than many poor countries in Africa today – we certainly have better written records about their rural activities than is often the case today (Bolt et al., 2018; Jerven, 2013). Thus, Western Europe was well above subsistence. Moreover, the part of agriculture that was for self-consumption will not appear in the GDP estimates, as is standard; hence, all the GDP variation which I capture must represent variation in market activity.

4.2. Placebo tests

If future variation in the production of precious metals was anticipated, agents should have engaged in intertemporal consumption smoothing and we should observe some GDP growth prior to the arrival of the metals (even if credit constraints could imply that people were limited in their borrowing capacity). If current variation in the annual production of precious metals was instead not well anticipated in previous years, as I argue, then an increase in the current value of metals production cannot influence past GDP growth.

Figure 15 comprises a Jordà method placebo test to confirm this. The figure shows the growth of real GDP over past years as a result of a change in the current shock variable.[59] For example, at the x-axis value of -2, the figure shows how current monetary shocks affect the real

[57]Studies of premodern price nominal rigidity are few in number, but those that exist suggest that this was the case in other contexts as well (Brzezinski et al., 2019; Velde, 2009).

[58]We cannot extrapolate current cross-country evidence across poor and rich countries back in time and assume that the sectorial composition in poor countries today is a good indicator of sectorial compositions more than two hundred years ago. In England, for example, the industrial and service sectors already accounted for 40% of the labor force in 1381, and by 1759 agriculture's share of the labor force had shrunk to 37% (Broadberry et al., 2013). Wallis et al. (2018) also show, using a different methodology, that by the early eighteenth century only around 45% of the male labor force were in agriculture. In Portugal, the size of the population working in the nonagricultural sector was always above 30% from 1500 onward, reaching 46.5% around 1750 (Palma and Reis, 2019). The share of nonagricultural GDP would have been even higher, since nonagricultural workers had higher labor productivity than those working in agriculture (Palma and Reis, 2019). It is hence certain that the total share of nonagricultural GDP in premodern Portugal was above 50%. (This includes not only urban workers but also people working outside of agriculture in rural areas, e.g. proto-industry and rural services).

[59]The specification is the same as in the main regression results, with the exception that past values of the dependent variable cannot be included because they are collinear with the left-hand side variable.

GDP growth over the past two years. If future monetary shocks were unpredictable and hence unrelated to current GDP, we would expect current shocks not to be able to predict past real GDP growth levels. Figure 15 shows that this is the case.

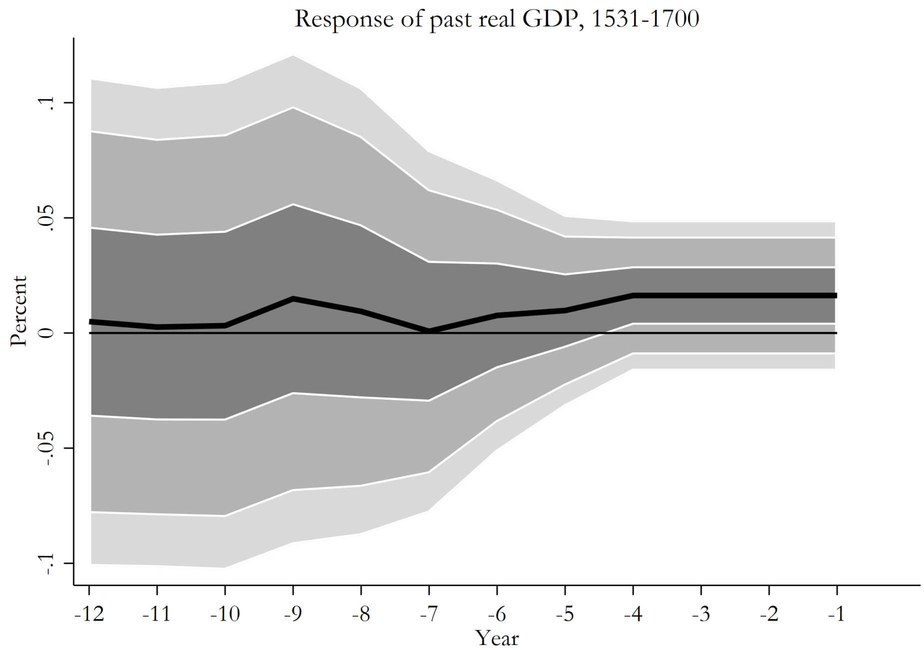

Figure 15: Placebo test for the response of past growth of real GDP to an increase in current precious metals, using the Jordà (2005) local projection method (1531-1700). The graph shows how the past growth from the years indicated on the x-axis responds to an increase in current precious metals. Country fixed effects are included, and standard errors are clustered by country to control for correlation in the error term across years. One standard deviation, 90% and 95% confidence intervals are shown. Control variables follow the main specification with the exception that past lagged dependent variables cannot be included. Sources: see text.

4.3. Did European GDP cause changes in the production of precious metals?

Another endogeneity concern is that mining in America could have reacted to the state of the European economy. The literature on the nineteenth-century gold standard assumes that gold production was indeed endogenous: the model used by Barro (1979) describes the adjustment of money and prices under the gold standard, assuming that the supply of gold in the long run was determined by the opportunity cost of producing gold. Hence, if there was a rise in productivity in the non-gold producing sector of the economy, there was a subsequent increase in the demand for money. In turn, this leads to a fall in prices (i.e. to a rise in the purchasing power of gold), which stimulates gold production.[60] It could also be the case that conditions in Europe might have an impact on the intensity of explorations, for instance by limiting the funding of the explorers in bad times.

[60]It would be interesting to test these theoretical predictions for the period Barro was writing about using the timing of the discovery and mining intensity of nineteenth century gold rushes in Alaska, Russia, Australia, South Africa, and California. I leave this for future work.

I now test the reverse-causality hypothesis using a IV strategy for the whole panel of countries, relying on variation in incomes caused by the weather. In premodern Europe, growing season temperature influenced agricultural output (Galloway, 1986). This could lead to reverse causality from GDP to the production of precious metals. For example, suppose that in a given year, output increased due to good weather. This could cause increased money demand and potentially influence American production of precious metals, as suggested by the Barro (1979) model. I test this hypothesis in order to eliminate the confounding factor of reverse causality. For air temperature, I rely on a dataset which is built from a large number of sources including tree ring series, historical documents, ice-core isotopic series, and pollen-based series.[61] In the first stage, I regress GDP on temperature (and lags thereof), where I use country-specific air temperature, which is expressed in deviations from the 1961-90 average. In terms of the exclusion restriction, it seems reasonable to assume that the weather in Europe did not affect the production of precious metals in America via other channels in addition to (potentially) the differential levels of money demand caused by changes in GDP.

The first-stage results are shown in Table 4. As expected, the instruments are relevant, having a first-stage F-statistic of 19.56, well above the usual rule-of-thumb of 10.[62] There is a positive association between temperature and GDP: a 1 degree centigrade increase in average growing season temperature leads to 1.5% higher GDP in the same year, holding temperature in the previous two years constant. There are similar effects from lagged temperature. While the coefficients are not individually significant, they are jointly significant.

Dependent Variable: ln real GDP	First stage regression
Temperature	
Contemporaneous	0.015
	(0.021)
First lag	0.008
	(0.015)
Second lag	0.014
	(0.016)
F-statistic	19.56
Prob > F	0.0034

Table 4: First stage regression of lagged real GDP on lags of temperature. Sources: see text.

Figure 16 shows the second-stage results, which demonstrate that exogenous variation in real GDP did not cause an increase in the production of precious metals at any time horizon. Hence, these results suggest that the state of the European economy did not significantly influence future discoveries or mining intensity of precious metals in America.

[61] Anderson et al. (2017), who in turn partly rely on Guiot and Corona (2010).

[62] Notice also that the variables are jointly significant at the 1% significance level.

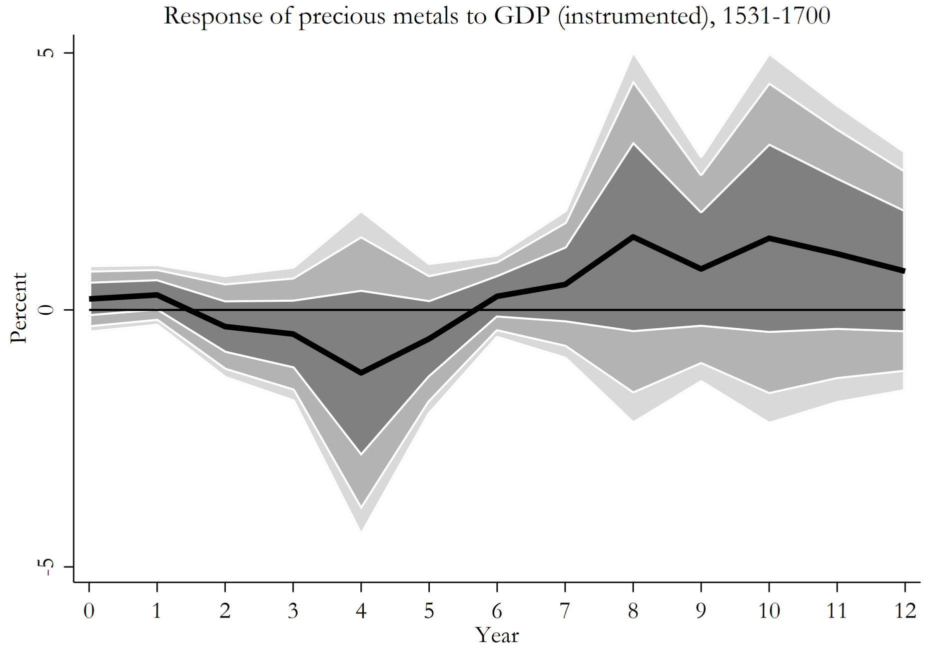

Figure 16: Local projecions showing the effect of GDP on the production of precious metals, with temperature as an instrument for GDP. Country fixed effects are included and standard errors are clustered by country to control for correlation in the error term across years. One standard deviation, 90% and 95% confidence intervals are shown. Sources: see text.

4.4. Accounting for endogenous formation of expectations

There are two further reasons why the shocks which resulted from American production of precious metals were exogenous and unanticipated. First, people were not in a position to know how much money was coming in. Second, even if they had the best-available information throughout, this information exhibited large errors on a yearly basis. This is important because if people could correctly estimate the size of the annual monetary injections to the European economy, any effects could be already priced in. I now argue each of these two points in turn.

People did not have access to information on the annual value of metals either being produced in America or arriving to Europe, even after their arrival. They were unable to know what the process in Figure 8 looked like. This is not only because they would not have known the numerator as the exact amounts were private information, but neither the denominator: the European precious metals stock. So, it would have been impossible to evaluate the relative magnitude of any given injection. Additionally, even if people formed expectations rationally, and were literate or had access to someone who was – and who could hence internalize the information given by the economic press of the time – such information was scarce. Still, certain newspapers did report on the arrivals; I will now show that the reported quantities were on average correct, but exhibited large errors in most years.[63]

[63]The most common theoretical way to obtain short-run neutrality of money assumes not only rational expectations but also instant market clearing. Even today markets do not clear instantly, because of various frictions

A comparison between the arrivals numbers given by the economic press of the time with the true arrivals shows that the annual unanticipated part of the shock was typically large. I construct my measure of the unanticipated component of the monetary increases as follows. Reports in the economic press announcing the arrival quantities represent the best information available at the time. One source which exists and has been studied in detail is that of the Dutch gazettes (Morineau, 2009). They reported how much silver and gold was arriving in Spain and Portugal every year.[64] In turn, for the case of eighteenth-century gold arrivals to Portugal, we know, on an annual basis, the true arrivals.[65] Hence, I define each annual innovation as the quantity that actually arrived minus that which a hypothetical best-informed agent might expect from relying on public information alone (Figure 17 shows the annual innovations, and Figure A29 in the appendix the original data in levels). In the initial decades, the newspapers exaggerated the quantities arriving, and there was some persistence in these mistakes, as visual inspection of Figure 17 suggests.[66] However, as the century advanced, the variance in these errors diminished, and the direction of the errors also became less systematic.

Figure 17 shows that the unanticipated component is centered around zero: the newspapers got average arrivals about right.[67] This is confirmed by the fact that the innovation series is white noise.[68] More importantly, the innovations are large relative to average arrivals.[69] This unanticipated part of the arrivals plays an important role: even for the well-informed, annual variation in precious metals arrivals constituted a shock, as agents could not predict well either variation in production levels in the Americas or annual arrivals to Europe, thus increasing the credibility of variation in my independent variable as exogenous, unpredictable shocks.

---

such as sticky plans, prices, and wages, and the same was true for the past; but early and accurate announcements about arrivals would have given more time for individual re-optimizations to take place.

[64] They represent an informational upper bound, i.e. the quantities that an hypothetical agent which was as well informed as they could possibly be and who formed expectations rationally, could best forecast.

[65] Brazilian gold formed a large fraction of the total value of gold arrivals to Europe during the eighteenth century (the gold surge after about 1700 is visible in Figure 7), and there is evidence that it then spread out all over Europe (Blanning, 2007, p.95). The data on gold arrivals was private information to the receiving agents and their intermediaries and to the king of Portugal, and has been obtained from a fiscal source, the *livros de manifestos de 1%*, available at the Lisbon mint. Costa, Rocha, and Sousa (2013) provide the data, which are available for the period 1720-1808, and contain information not only about the amounts arriving but also its receivers, both public and private. The *livros de manifestos de 1%* was compulsory for all the fleets that transported gold arriving from 1720 onward. Costa et al. (2013, p.20) argue persuasively that any quantities of gold smuggled must have been minor compared with those shipped officially, because 1% was a small cost once agency and transportation costs as well as decreased risk are taken into account.

[66] It seems, however, likely that the reverse would have been true earlier in the century, when the Brazilian discoveries were starting, but no data on the true arrivals is available prior to 1720.

[67] Notice that the resolution of the uncertainty was never known to the agents since the true quantities arriving remained, for them, unobservable. Since privately-owned individual quantities were often picked up by intermediaries, arguably communication between these could lead to a rough estimate of the totals. However, the very fact that commercial gazettes were providing these estimates suggests that the total quantities were not otherwise known to the public.

[68] Portmanteau and Bartlett's periodogram-based test for white noise both fail to reject the hypothesis of white noise at the 5% significance level (see Appendix Figure A30).

[69] The median annual value for arrivals during the 1720-1788 period was 7.26 tonnes of gold (Costa et al., 2013). Unfortunately, in the case of arrivals in Spain, an equivalent measure cannot be constructed. This is because while the Dutch gazettes also reported quantities of Spanish American gold arriving to Europe, no source analogous to the *livros de manifestos de 1%* is available in the Spanish American case (Costa et al., 2013), rendering an analogous calculation of the innovations impossible for that case. But there seems to be no good reason to suppose that the Dutch gazettes were able to predict quantities coming from Spanish America any better than they were in the Brazilian case.

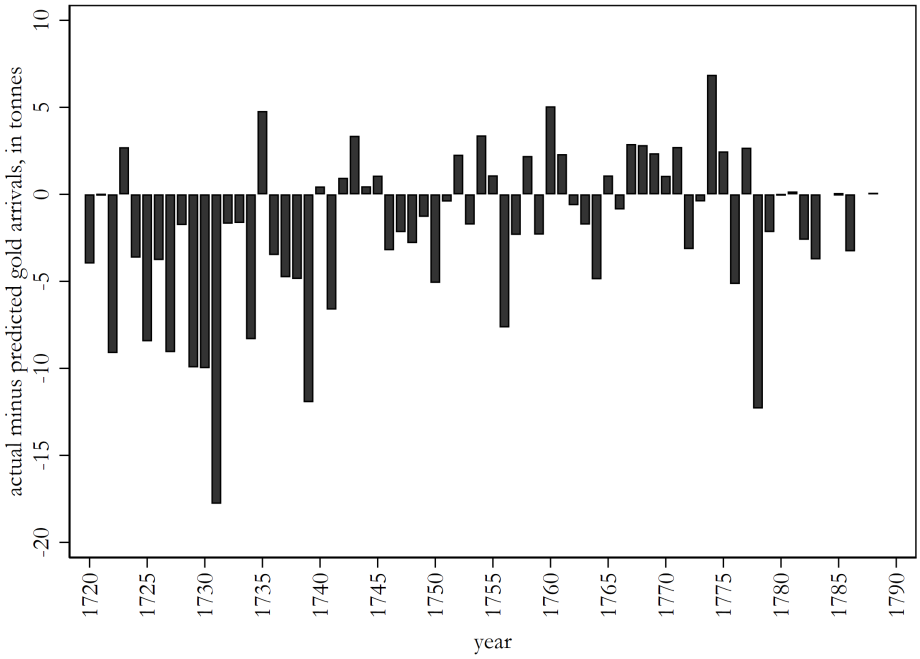

Figure 17: A lower bound to the innovation component of gold arrivals, in tonnes (defined as true arrivals, given by a source that was private information, minus the best-information higher-bound expectation, given by a source which was public information). Sources: see text.

5. Conclusion

Identification in macroeconomics is elusive: convincing natural experiments or instrumental variables that allow us to answer important questions are rarely available (Nakamura and Steinsson, 2018a). In the case of the identification of the effects of money on the real economy, an extensive literature has developed, but the fact that causal effects are so difficult to identify has led to all sorts of conclusions, ranging from monetary shocks having no effects (Sims and Zha, 2006; Uhlig, 2005) to them having small-to-moderate and persistent effects (Christiano, Eichenbaum, and Evans, 1999), to strong and very persistent effects (Arias et al., 2019; Gertler and Karadi, 2015; Romer and Romer, 2004).

The early modern monetary injections from America provide a source of identification for monetary non-neutrality.[70] While restricted to a period of the past, the evidence supports the notion of non-neutrality, and is in favor of large, and persistent, effects of money on real output. Still, the considerations in this paper have been concerned with the internal validity of the results, as opposed to the degree to which they may be informative about modern economies. The safest interpretation is that the timing and magnitude of the effects that I find apply only to the context of the early modern European economy; the fact that early modern economies

[70] I do not take an active position in this paper on what was the mechanism through which money affected real economic activity. Data on money market interest rates is not systematically available or directly observed for these economies, and more than one type of monetary transmission mechanism is consistent with these results. See, however, Brzezinski et al. (2019), who find liquidity effects using interest rates recovered from bill of exchange contracts.

were different from those of today certainly precludes direct extrapolation of the results. It is difficult to know at this stage, for instance, whether prices were more or less sticky than in modern economies since qualitatively, an argument could be made both ways; to my knowledge, no study has undertaken a systematic comparison of wage and price rigidities in the past vis-à-vis modern economies. On the one hand, in early modern economies social norms could lead to price and wage rigidities as well as market illiquidity. Land contracts, for instance, were often set for several generations. And unlike today, in the early modern period nominal wages (though not prices) only varied intermittently, often staying constant over an interval of many years. But at the same time, in modern economies most prices (but not wages) seem to vary considerably less than they did in the past, perhaps due to the stabilizing influence of modern central banks. And yet it is striking that the response of past economies to monetary shocks was as qualitatively similar as it was to what some macroeconomists expect for modern economies; see, for example, Wolf (2020).

Many extensions of this work are possible for the future. For some countries it is possible to split the output data into agricultural versus non-agricultural (industry and service) sectors, but as more and better data becomes available this will be possible for more countries. It seems possible that the effects are faster and stronger for the latter sectors, which would then suggest that the full results are to a large degree being driven by an elastic response of industry and services, even if agriculture also responded to some degree. Another promising avenue is to consider whether the effects are conditional on the state of the economy, e.g. stronger at times of recession. That exercise is not straightforward since a definition of "recession" for premodern economies is far from clear-cut, and the annual frequency of the data allows us only to consider episodes where the recessions lasted at least one year. Still, one possibility would be to define recession as periods below trend growth, which would allow us to consider whether the effects change conditional on the receiving economy being in recession (Jordà et al., 2020; Ramey and Zubairy, 2018; Thwaites and Tenreyro, 2016). Finally, my emphasis in this paper has been on reduced-form results but there is related work that tries to understand the structural mechanism behind them (Brzezinski et al., 2019).

References

Allen, R. C. The great divergence in European wages and prices from the Middle Ages to the First World War. *Explorations in Economic History*, 38(4):411–447, 2001.

Álvarez-Nogal, C. and Prados de la Escosura, L. The rise and fall of Spain (1270-1850). *The Economic History Review*, 66(1):1–37, 2013.

Álvarez-Nogal, C. and Prados de la Escosura, L. Long-run GDP estimates for Spain, 1277-1850. *Unpublished manuscript*, 2017.

Álvarez-Nogal, C., Prados De La Escosura, L., and Santiago-Caballero, C. Spanish agriculture in the little divergence. *European Review of Economic History*, 20(4):452–477, 2016.

Anderson, R. W., Johnson, N. D., and Koyama, M. Jewish persecutions and weather shocks: 1100–1800. *The Economic Journal*, 127(602):924–958, 2017.

Angrist, J. D. and Kuersteiner, G. M. Causal effects of monetary shocks: Semi-parametric conditional independence tests with a multinomial propensity score. *Review of Economics and Statistics*, 93(3):725–747, 2011.

Arias, J. E., Caldara, D., and Rubio-Ramirez, J. F. The systematic component of monetary policy in SVARs: An agnostic identification procedure. *Journal of Monetary Economics*, 101: 1–13, 2019.

Bacci, M. L. *El Dorado in the marshes: Gold, slaves and souls between the Andes and the Amazon.* Polity, 2010.

Bakewell, P. J. *Silver mining and society in colonial Mexico, Zacatecas 1546-1700.* Cambridge University Press, 1971.

Bakewell, P. J. Technological change in Potosí: The silver boom of the 1570's. In Konetzke, R. and Kellenbenz, H., editors, *Jahrbuch fur Geschichte von Staat, Wirtschaft und Gesellschaft Lateinsamerikas XIV.* Verlang, 1977.

Barakchian, S. M. and Crowe, C. Monetary policy matters: Evidence from new shocks data. *Journal of Monetary Economics*, 60(8):950–966, 2013.

Barrandon, J., Morrisson, C., and Cécile, M. Or du Brésil, monnaie et croissance en France au XVIIIe siècle. In *Cahiers Ernest Babelon*, volume 7. Paris: CNRS Editions, 1999.

Barret, W. World bullion flows, 1450-1800. In *The Rise of Merchant Empires.* Cambridge University Press, 1990.

Barro, J. Money and the price level under the gold standard. *The Economic Journal*, 89:13–33, 1979.

Blanning, T. *The pursuit of glory: Europe, 1648-1815.* Penguin, 2007.

Blinder, A., Canetti, E. R., Lebow, D. E., and Rudd, J. B. *Asking about prices: a new approach to understanding price stickiness.* Russell Sage Foundation, 1998.

Bolt, J., Inklaar, R., de Jong, H., and van Zanden, J. L. Rebasing Maddison: Relative prices and the shape of long-run global development. GGDC Research Memorandum, vol.: GD-174, Groningen Growth and Development Centre, 2018.

Boxer, C. R. *The Golden Age of Brazil: Growing Pains of a Colonial Society, 1695-1750.* University of California Press, 1962.

Broadberry, S., Campbell, B. M., and van Leeuwen, B. When did Britain industrialise? The sectoral distribution of the labour force and labour productivity in Britain, 1381–1851. *Explorations in Economic History*, 50(1):16–27, 2013.

Broadberry, S., Campbell, B., Klein, A., Overton, M., and van Leeuwen, B. *British Economic Growth, 1270-1870.* Cambridge University Press, 2015a.

Broadberry, S., Custodis, J., and Gupta, B. India and the Great Divergence: An Anglo-Indian comparison of GDP per capita, 1600-1871. *Explorations in Economic History*, 55:58–75, 2015b.

Brzezinski, A., Chen, Y., Palma, N., and Ward, F. The vagaries of the sea: evidence on the real effects of money from maritime disasters in the Spanish Empire. Discussion Paper 14089, CEPR, 2019.

Cameron, R. England, 1750-1844. In Cameron, R., editor, *Banking in the Early Stages of Industrialization: A Study in Comparative Economic History*, pages 15–59. Oxford University Press, 1967.

Capie, F. Money and economic development in England. In de la Escosura, L. P., editor, *Exceptionalim and industrialization.* Cambridge University Press, 2004.

Challis, C. *The Tudor Coinage.* Manchester University Press, 1978.

Challis, C. Lord Hastings to the great silver recoinage 1464-1699. In Challis, C., editor, *New History of the Royal Mint.* Cambridge University Press, 1992.

Chari, V., Kehoe, P., and McGrattan, E. Are structural vars with long-run restrictions useful in developing business cycle theory? *Journal of Monetary Economics*, 55:1337–1352, 2008.

Christiano, L. J., Eichenbaum, M., and Evans, C. L. Monetary policy shocks: what have we learned and to what end? *Handbook of Macroeconomics*, 1(65), 1999.

Christiano, L. J., Eichenbaum, M., and Evans, C. L. Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, 113(1):1–45, 2005.

Clodfelter, M. *Warfare and armed conflicts: a statistical reference to casualty and other figures 1494-2007.* McFarland, 2008.

Cloyne, J. and Hürtgen, P. The macroeconomic effects of monetary policy: a new measure for the United Kingdom. *American Economic Journal: Macroeconomics*, 8(4):75–102, 2016.

Coibion, O. Are the effects of monetary policy shocks big or small? *American Economic Journal: Macroeconomics*, 4(2):1–32, 2012.

Costa, L. F., Rocha, M. M., and Sousa, R. *O Ouro do Brasil*. Imprensa Nacional-Casa da Moeda, 2013.

Costa, L. F., Rocha, M. M., and Brito, P. B. The alchemy of gold: interest rates, money stock, and credit in eighteenth-century Lisbon. *The Economic History Review*, 2017.

de Jong, H. and Palma, N. Historical national accounting. In Blum, M. and Colvin, C., editors, *An Economist's Guide to Economic History*. Palgrave Macmillan, 2018.

Deaton, A. and Muellbauer, J. An almost ideal demand system. *American Economic Review*, 312-326, 1980.

Desaulty, A. M. and Albarede, F. Copper, lead, and silver isotopes solve a major economic conundrum of Tudor and early Stuart Europe. *Geology*, 41(2):135–138, 2013.

Desaulty, A. M., Telouk, P., Albalat, E., and Albarede, F. Isotopic Ag–Cu–Pb record of silver circulation through 16th–18th century Spain. *Proceedings of the National Academy of Sciences*, 108(22):9002–9007, 2011.

Dyer, C. *Making a living in the middle ages: the people of Britain 850-1520*. Yale University Press, 2002.

Elliott, J. H. *Empires of the Atlantic world: Britain and Spain in America, 1492-1830*. Yale University Press, 2006.

Elsas, M. J. *Umriss einer Geschichte der Preise und Löhne in Deutschland: vom Ausgehenden Mittelater bis zum Beginn des neunzehnten Jahrhunderts*. Leiden: A. W. Sijthoff's Utgeversmaatschappij, 1940.

Federico, G. How much do we know about market integration in Europe? *The Economic History Review*, 65(2), 2011.

Felloni, G. *Il Monete Genovesi*. Sringa, 1976.

Figueiredo, L. *A última pepita: os Portugueses e a corrida ao ouro do Brasil*. Marcador, 2012.

Flandreau, M. *The glitter of gold: France, bimetallism, and the emergence of the international gold standard, 1848-1873*. Oxford University Press, 2004.

Friedman, M. and Schwartz, A. J. *A monetary history of the United States, 1867-1960*. Princeton University Press, 1963.

Galloway, P. Long-term fluctuations in climate and population in the preindustrial era. *Population and Development Review*, 12(1):1–24, 1986.

Gardner, R. Long-term silver mining trends in Spanish America: A comparative analysis of Peru and Mexico. *American Historical Review*, 93(4), 1988.

Gertler, M. and Karadi, P. Monetary policy surprises, credit costs, and economic activity. *American Economic Journal: Macroeconomics*, 7(1):44–76, 2015.

Gonzalez, A. G.-B. Las remesas de metales preciosos Americanos en el siglo XVIII: una aritmética controvertida. *Hispania*, 56(192):203–266, 1996.

Guiot, J. and Corona, C. Growing season temperatures in Europe and climate forcings over the past 1400 years. *PLoS One*, 5(4), 2010. URL `www.ncdc.noaa.gov/paleo/recons.html`.

Hamilton, E. J. *American treasure and the price revolution in Spain, 1501-1650*, volume 1125. Harvard University Press Cambridge, MA, 1934.

Irigoin, M. The end of a silver era: the consequences of the breakdown of the Spanish peso standard in China and the United States, 1780s–1850s. *Journal of World History*, 20(2): 207–244, 2009.

Irigoin, M. The new world and the global silver economy. In Riello, G. and Roy, T., editors, *Global Economic History*. Bloomsbury, 2018.

Jara, A. La producción de metales preciosos en el Perú en el siglo XVI. *Boletín de la Universidad de Santiago de Chile 44, November*, 1963.

Jara, A. *Tres Ensayos sobre Economía Minera Hispanoamericana*. Santiago de Chile: Prensas de la editorial universitaria, S. A., 1966.

Jarociński, M. and Karadi, P. Deconstructing monetary policy surprises—the role of information shocks. *American Economic Journal: Macroeconomics*, 12(2):1–43, 2020.

Jerven, M. *Poor numbers: how we are misled by African development statistics and what to do about it*. Cornell University Press, 2013.

Jordà, O. Estimation and inference of impulse responses by local projections. *American Economic Review*, 95(1):161–182, 2005.

Jordà, O., Schularick, M., and Taylor, A. M. The effects of quasi-random monetary experiments. *Journal of Monetary Economics*, 112:22–40, 2020.

Karaman, K. K., Pamuk, S., and Yildirim, S. Money and monetary stability in Europe, 1300-1914. *Journal of Monetary Economics*, 2019.

Kaur, S. Nominal wage rigidity in village labor markets. *American Economic Review*, 109(10): 3585–3616, 2019.

Leeper, E. Narrative and VAR approaches to monetary policy: Common identification problems. *Journal of Monetary Economics*, 340(3):641–657, 1997.

Malanima, P. L'economia Italiana: Dalla crescita medievale alla crescita contemporanea, Bologna, il Mulino. 2002.

Malanima, P. The long decline of a leading economy: GDP in central and northern Italy, 1300-1913. *European Review of Economic History*, 15:169–219, 2011.

Marx, R. F. *Shipwrecks in the Americas.* Courier Corporation, 1987.

Mayhew, N. *Sterling: the rise and fall of a currency.* Allen Lane, 1999.

Mayhew, N. Prices in England 1170-1750. *Past and Present*, 219(1):3–39, 2013.

McCloskey, D. N. and Zecher, J. R. How the gold standard worked. In Frenkel, J. A. and Johnson, H., editors, *The Monetary Approach to the Balance of Payments.* George Allen & Unwin, 1976.

Miranda-Agrippino, S. and Ricco, G. The transmission of monetary policy shocks. Discussion Paper 13396, CEPR, 2018.

Moesgaard, J. American silver and Europe. In *Europe Meets the World.* National Museum of Denmark, 2012.

Morineau, M. *Incroyables Gazettes et Fabuleux Métaux: Les Retours des Trésors Américains d'Après les Gazettes Hollandaises (XVI-XVII Siècles).* Cambridge University Press, 2009.

Morineau, M. Les frappes monétaires françaises de 1726 à 1793: Premières considérations. *Études d'histoire monétaire, Presses Univ. Septentrion*, pages 69–141, 1984.

Motomura, A. New data on minting, seigniorage, and the money supply in Spain (Castile), 1597-1643. *Explorations in Economic History*, 34(3):331–367, 1997.

Murphy, A. L. *The origins of English financial markets: investment and speculation before the South Sea Bubble.* Cambridge University Press Cambridge, 2009.

Nakamura, E. and Steinsson, J. Identification in macroeconomics. *Journal of Economic Perspectives*, 2018a.

Nakamura, E. and Steinsson, J. High-frequency identification of monetary non-neutrality: the information effect. *The Quarterly Journal of Economics*, 133(3):1283–1330, 2018b.

Nickell, S. Biases in dynamic models with fixed effects. *Econometrica*, pages 1417–1426, 1981.

Nightingale, P. Monetary contraction and mercantile credit in Later Medieval England. *The Economic History Review*, 48, 1990.

O'Brien, P. K. and Palma, N. Danger to the old lady of Threadneedle Street? The bank restriction act and the regime shift to paper money, 1797–1821. *European Review of Economic History*, 24(2):390–426, 2020.

Palma, N. Reconstruction of money supply over the long run: the case of England, 1270-1870. *The Economic History Review*, 71(2):373–392, 2018a.

Palma, N. Money and modernization in early modern England. *Financial History Review*, 25 (3):231–261, 2018b.

Palma, N. American precious metals and their consequences for early modern Europe. In Battilossi, S., Cassis, Y., and Kazuhiko, Y., editors, *Handbook of the History of Money and Currency*. Springer, 2019.

Palma, N. Historical account books as a source for quantitative history. In Christ, G. and Roessner, P., editors, *History and Economic Life: A Student's Guide to approaching Economic and Social History sources*. Routledge, 2020.

Palma, N. and Reis, J. From convergence to divergence: Portuguese economic growth, 1527-1850. *Journal of Economic History*, 79(2):477–506, 2019.

Palma, N. and Silva, A. Spending a windfall: American precious metals and Euro-Asian trade 1492-1815. Working paper, GGDC, 2016.

Pfister, U. The timing and pattern of real wage divergence in pre-industrial Europe: evidence from Germany, c. 1500–1850. *The Economic History Review*, 70(3):701–729, 2017.

Pfister, U. Economic Growth in Germany, 1500-1800. *Unpublished manuscript*, 2020.

Piketty, T. and Zucman, G. Capital is back: Wealth-income ratios in rich countries 1700–2010. *Quarterly Journal of Economics*, 129(3):1255–1310, 2014.

Porter, R. *The Penguin Social History of Britain: English Society in the Eighteenth Century*. Penguin, 1990.

Ramey, V. A. Macroeconomic shocks and their propagation. In *Handbook of Macroeconomics*, volume 2. Elsevier, 2016.

Ramey, V. A. and Zubairy, S. Government spending multipliers in good times and in bad: Evidence from U.S. historical data. *Journal of Political Economy*, 126(2):850–901, 2018.

Redish, A. *Bimetallism: An economic and historical analysis*. Cambridge University Press, 2000.

Romer, C. D. and Romer, D. Does monetary policy matter? A new test in the spirit of Friedman and Schwartz. In *NBER Macroeconomics Annual*, volume 4, pages 121–184. MIT Press, 1989.

Romer, C. D. and Romer, D. A new measure of monetary shocks: Derivation and implications. *American Economic Review*, pages 1055–1084, 2004.

Romer, D. *Advanced Macroeconomics*. McGraw-Hill Education, 2018.

Sargent, T. J. and Velde, F. R. Macroeconomic features of the French Revolution. *Journal of Political Economy*, 103(3):474–518, 1995.

Sargent, T. J. and Velde, F. R. *The Big Problem of Small Change*. Princeton University Press, 2002.

Sargent, T. J. and Surico, P. Two illustrations of the quantity theory of money: Breakdowns and revivals. *American Economic Review*, 101(1):109–128, 2011.

Sims, C. and Zha, T. Does monetary policy generate recessions? *Macroeconomic Dynamics*, 10 (2):231–272, 2006.

Sousa, R. *Moeda e metais preciosos no Portugal Setecentista (1688-1797)*. Imprensa Nacional da Casa da Moeda, 2006.

Spooner, F. *The international economy and monetary movements in France, 1493-1725*, volume 138. Harvard University Press, 1972.

Stampel, R. Coin Production in the Low Countries 14th-19th c. *IISH Dataverse*, 2016. URL `http://hdl.handle.net/10622/D5WXZZ`.

Stock, J. and Watson, M. Twenty years of time series econometrics in ten pictures. *Journal of Economic Perspectives*, 31(2):59–86, 2017.

Stock, J. H. and Watson, M. W. Identification and estimation of dynamic causal effects in macroeconomics using external instruments. *The Economic Journal*, 128(610):917–948, 2018.

Teles, P., Uhlig, H., and Azevedo, J. Is quantity theory still alive? *The Economic Journal*, 126 (591):442–464, 2016.

TePaske, J. *A New World of Gold and Silver*. Brill, 2010.

The Economist. China and Africa: Little fear but fear itself, September 2013.

Thwaites, G. and Tenreyro, S. Pushing on a string: U.S. monetary policy is less powerful in recessions. *American Economic Journal: Macroeconomics*, 2016.

Tobin, J. Money and income: post hoc ergo propter hoc? *The Quarterly Journal of Economics*, pages 301–317, 1970.

Tortella, G. and Ruiz, J. L. G. *Spanish money and banking: A history*. Springer, 2013.

Uhlig, H. What are the effects of monetary policy on output? Results from an agnostic identification procedure. *Journal of Monetary Economics*, 52:381–419, 2005.

van Zanden, J. L. *The long road to the industrial revolution: the European economy in a global perspective, 1000-1800*. Brill, 2009.

van Zanden, J. L. and van Leeuwen, B. Persistent but not consistent: The growth of national income in Holland 1347-1807. *Explorations in Economic History*, 49:119–130, 2012.

Velde, F. R. Chronicle of a deflation unforetold. *Journal of Political Economy*, 117(4):591–634, 2009.

Velde, F. R. and Weber, W. A model of bimetallism. *Journal of Political Economy*, 108(6): 1210–1234, 2000.

Vilar, P. *A History of Gold and Money 1450-1920.* Verso (originally published 1976), 2nd edition, 2011.

Wallis, P., Colson, J., and Chilosi, D. Puncturing the Malthus delusion: structural change in the British economy before the industrial revolution, 1500-1800. *Journal of Economic History*, 2018.

Wolf, C. K. SVAR (mis-) identification and the real effects of monetary policy shocks. *American Economic Journal: Macroeconomics*, 2020.

Wooldridge, J. M. *Introductory Econometrics: a modern approach.* Cengage Learning, Canada, 2009.

Wrigley, E. A. Urban growth and agricultural change: England and the continent in the early modern period. In *The Eighteenth-Century Town*, pages 47–90. Routledge, 2014.

Zuijderduijn, J., Stapel, R., and Lucassen, J. Coin production in the Low Countries: Fourteenth Century to the present. *Tijdschrift voor Sociale en Economische Geschiedenis – Low Countries Journal of Social and Economic History*, 15(2-3):69–88, 2018.

Appendix

to *"The existence and persistence of monetary non-neutrality: evidence from a large-scale historical natural experiment"*

Nuno Palma[1]

[1]Department of Economics, University of Manchester; ICS, Universidade de Lisboa; CEPR

A. Appendix figures

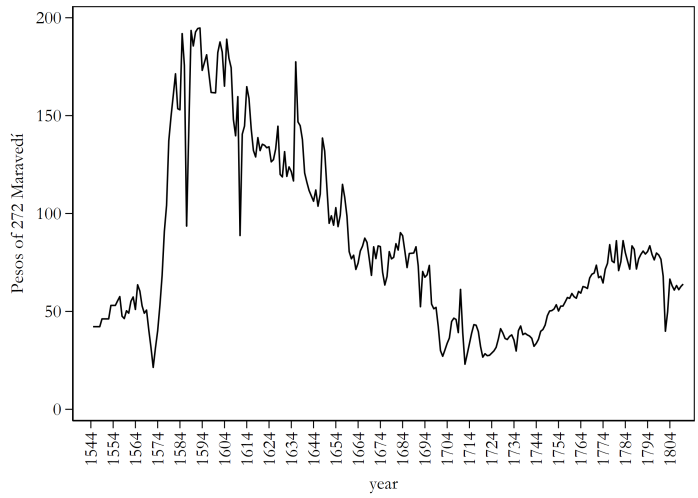

Figure A1: The long-term trends of Potosí silver output. Source: TePaske (2010).

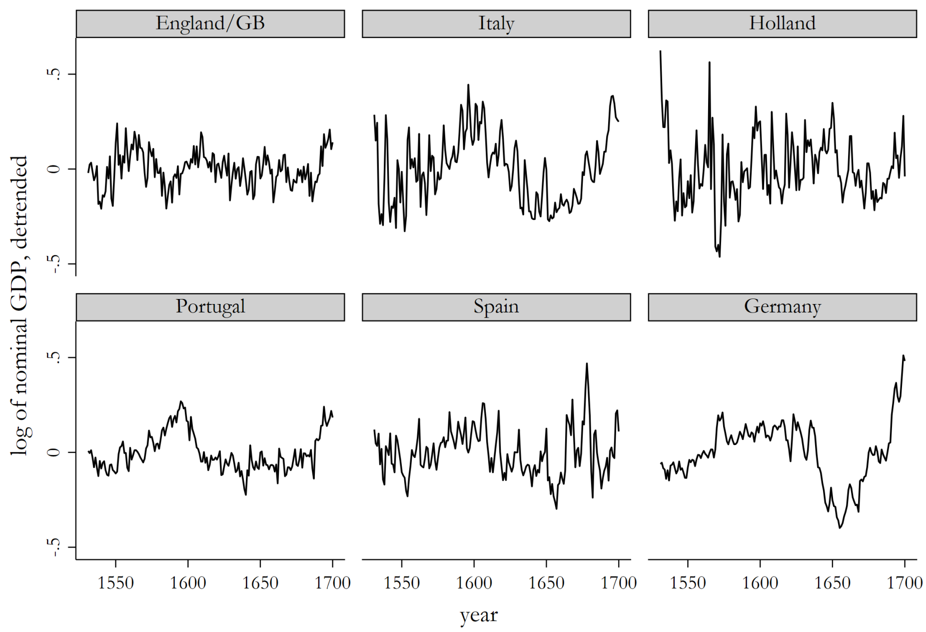

Figure A2: Nominal GDP, in logs and detrended. Sources: see text.

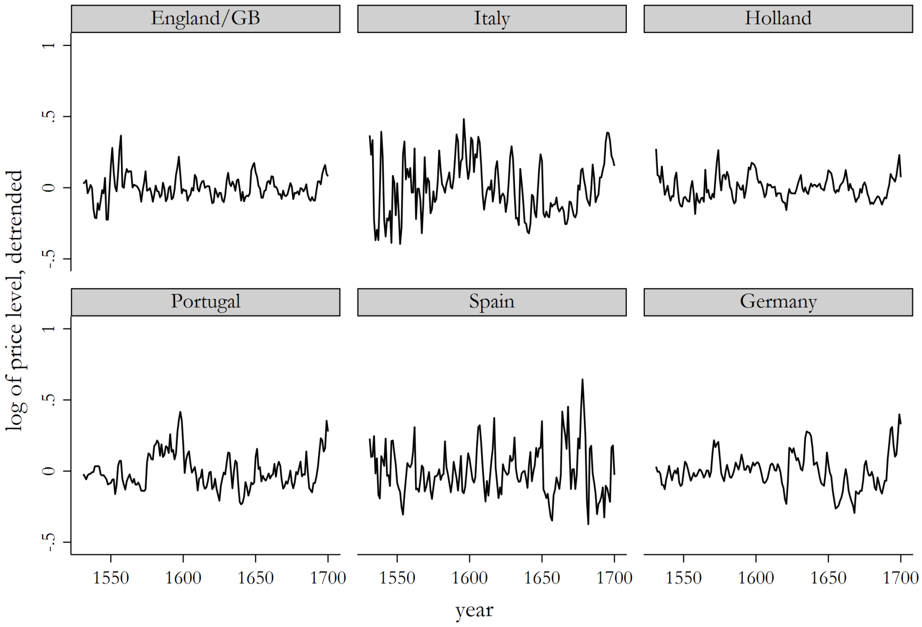

Figure A3: Prices, in logs and detrended. Sources: see text.

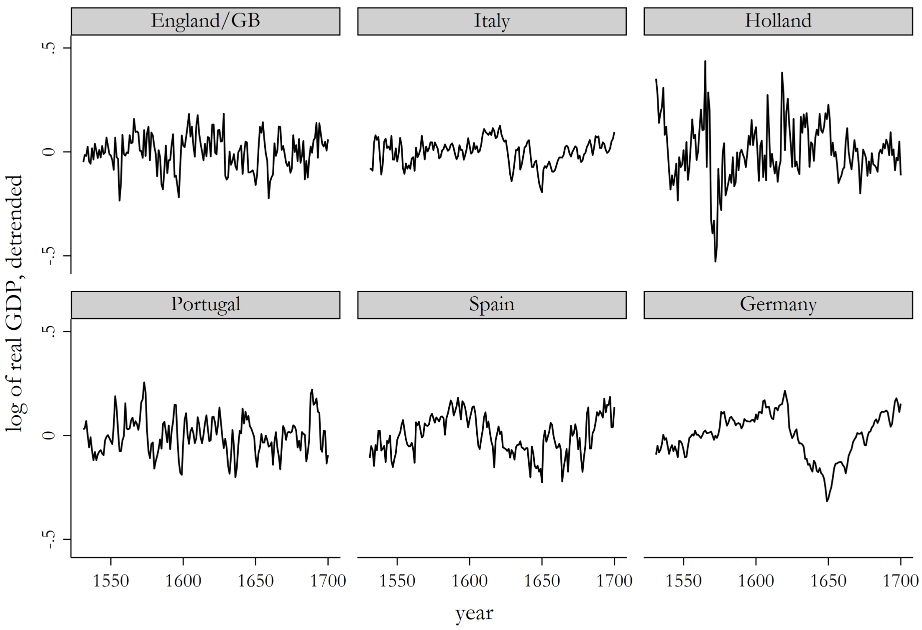

Figure A4: Real GDP, in logs and detrended. Sources: see text.

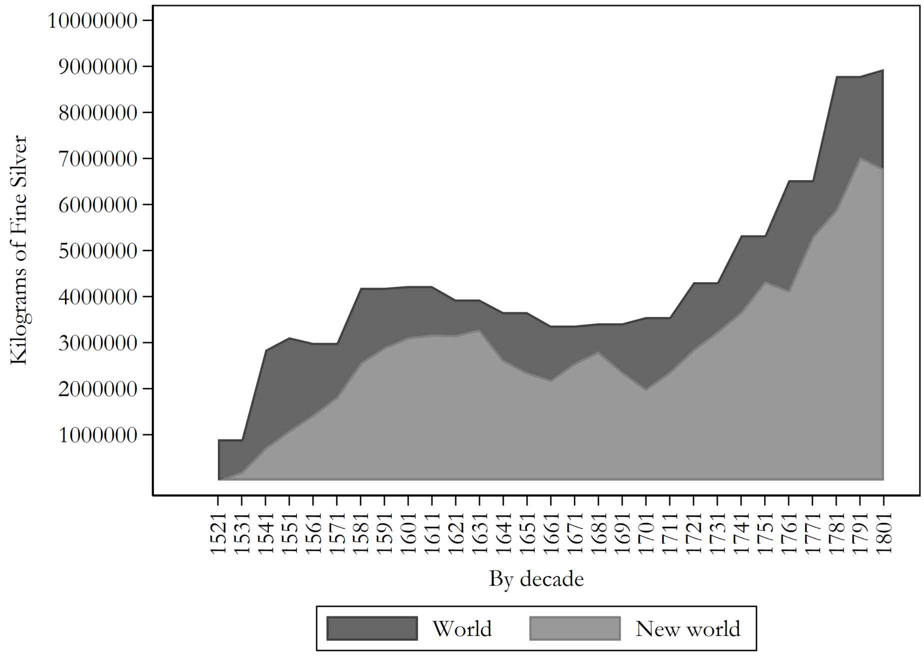

Figure A5: World vs. New World silver output, 1521-1810, in kg (by decade). Source: TePaske (2010, p.111) and Jara (1966).

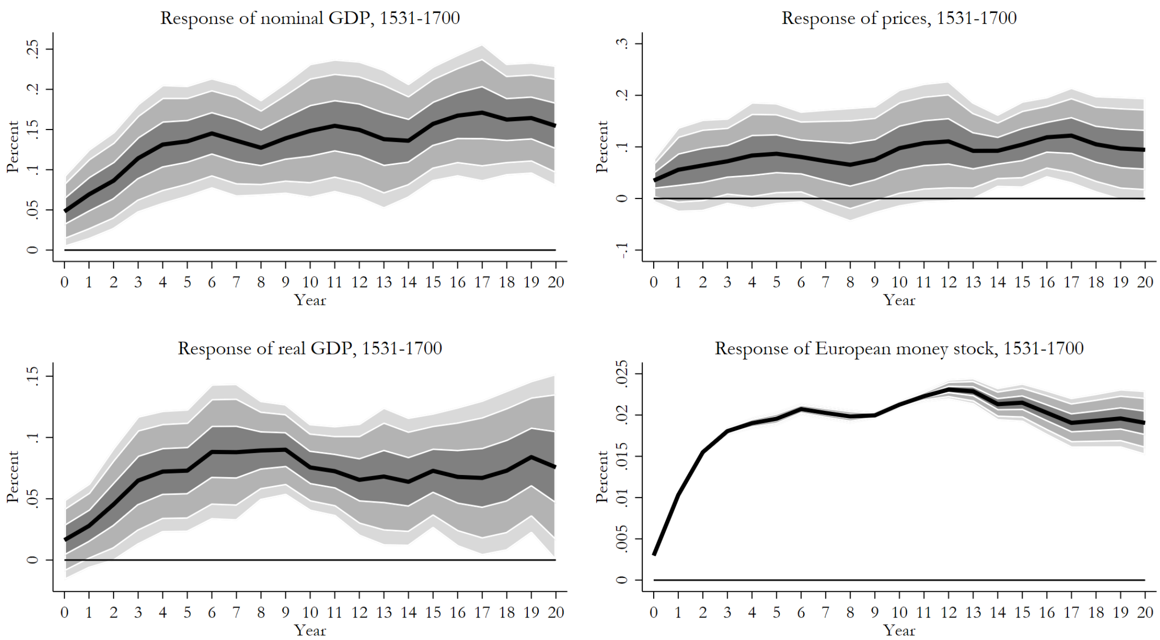

Figure A6: Robustness check: Horizon up to 20.

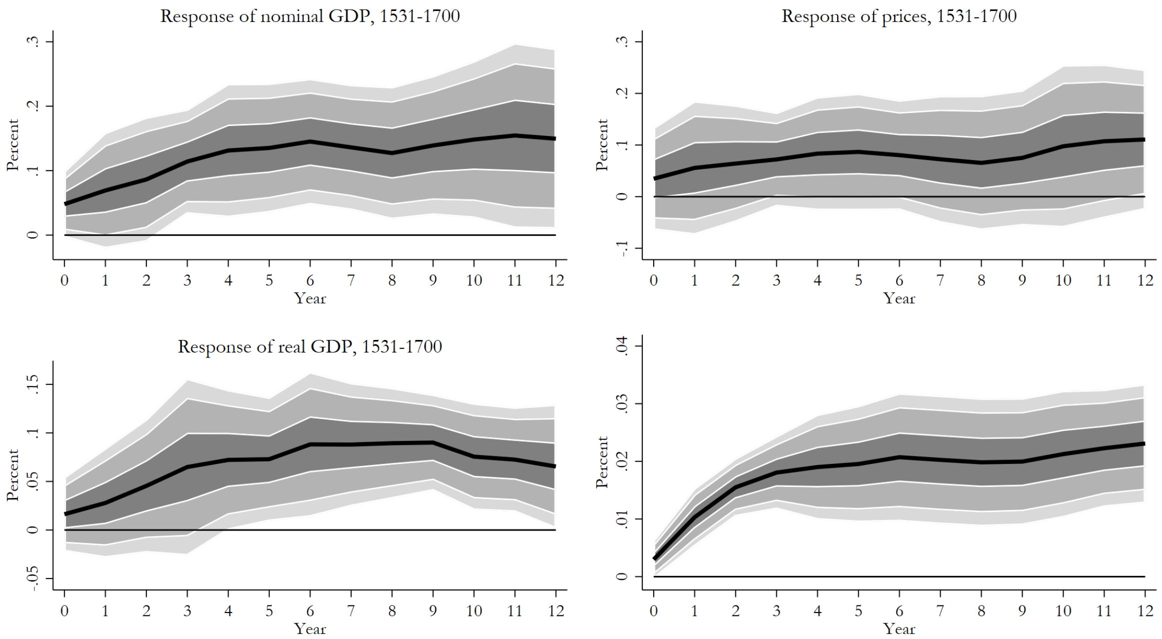

Figure A7: Robustness check: same specification as baseline, except robust standard errors are two-way clustered by country and year.

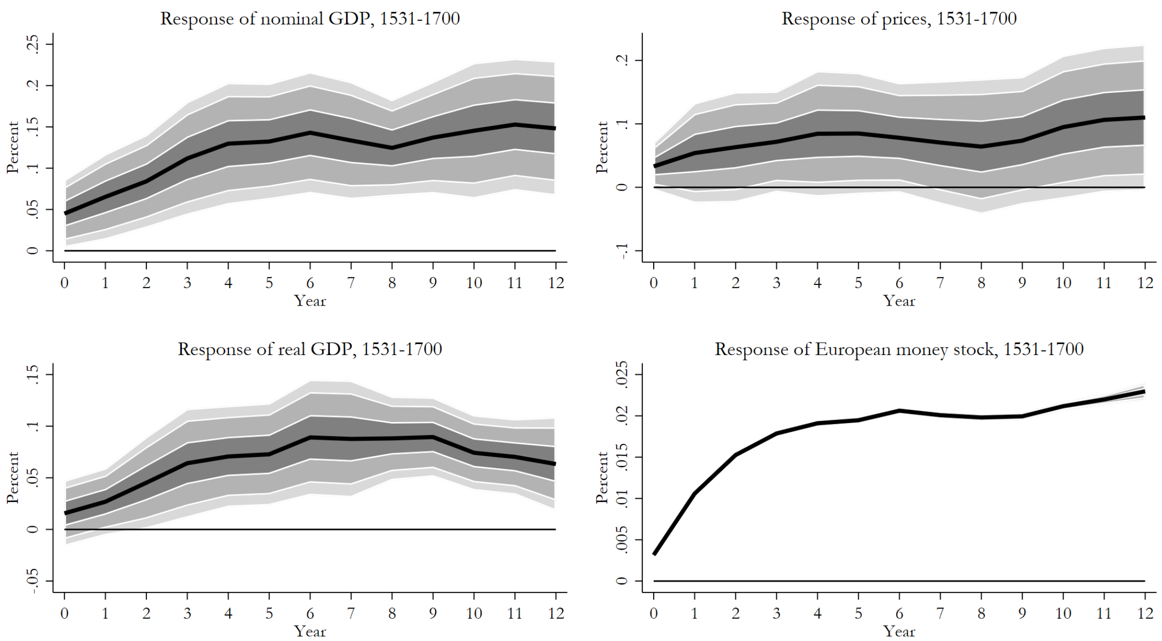

Figure A8: Robustness check: same specification as baseline, except no temperature controls.

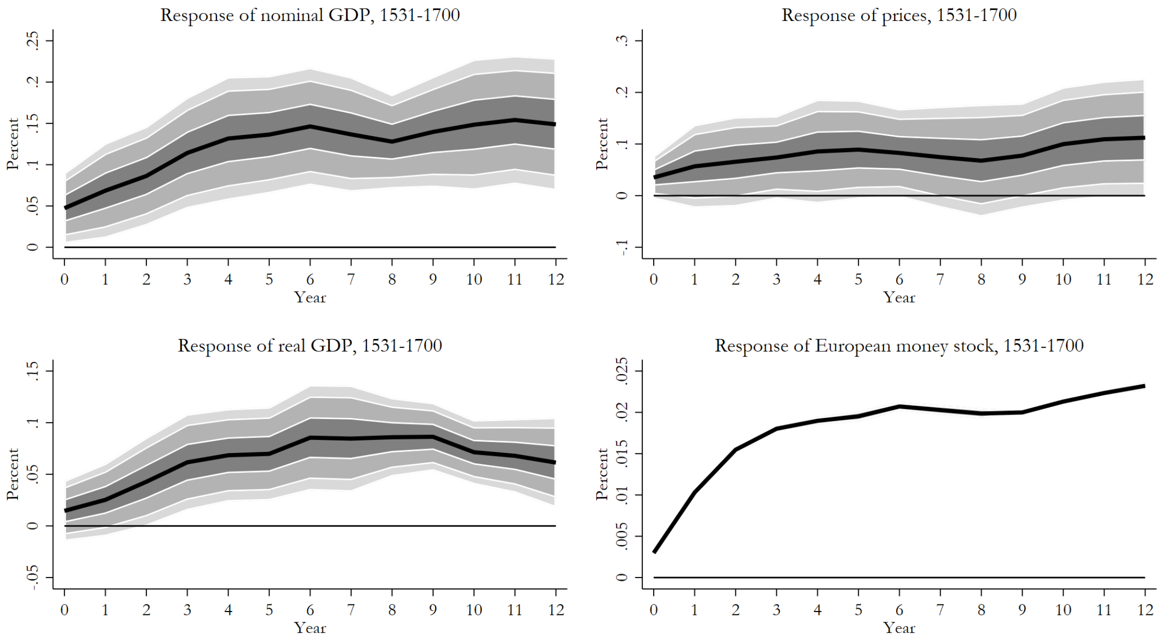

Figure A9: Robustness check: same specification as baseline, except no war with Spain control.

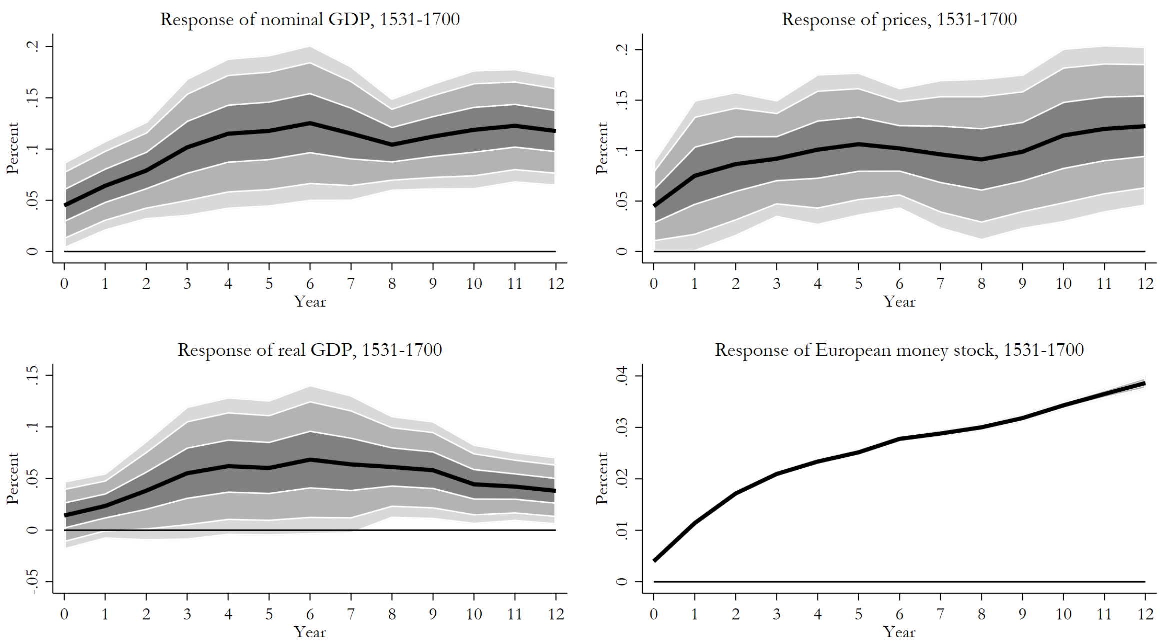

Figure A10: Robustness check: same specification as baseline, except no quadratic trend control.

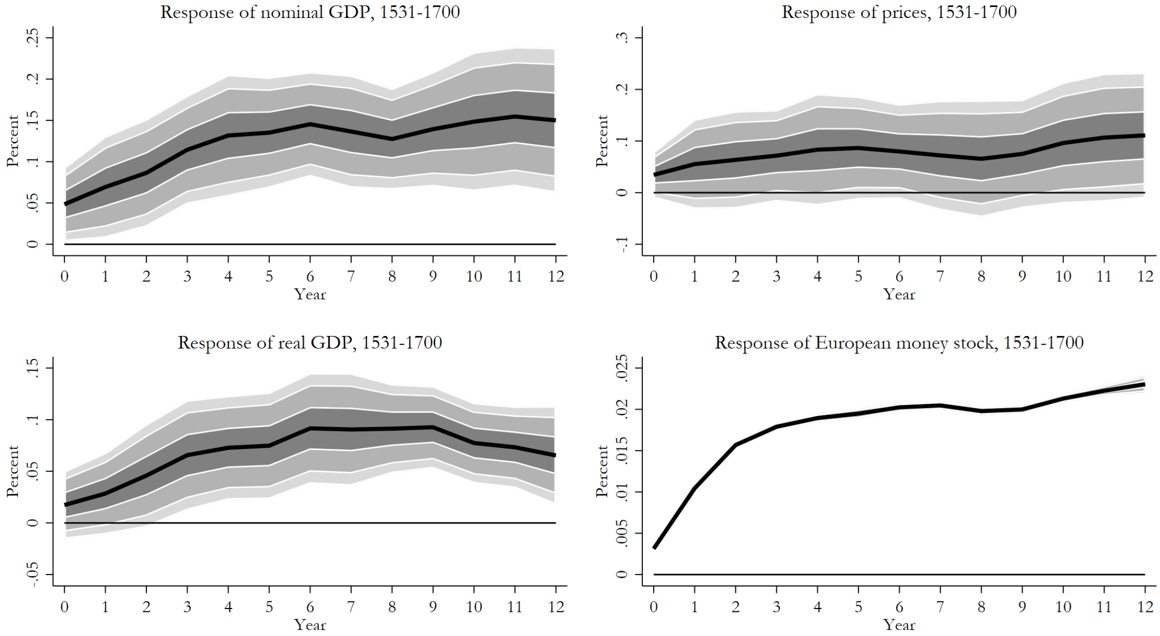

Figure A11: Robustness check: same specification as baseline, except 2 instead of 4 lags of dependent variables.

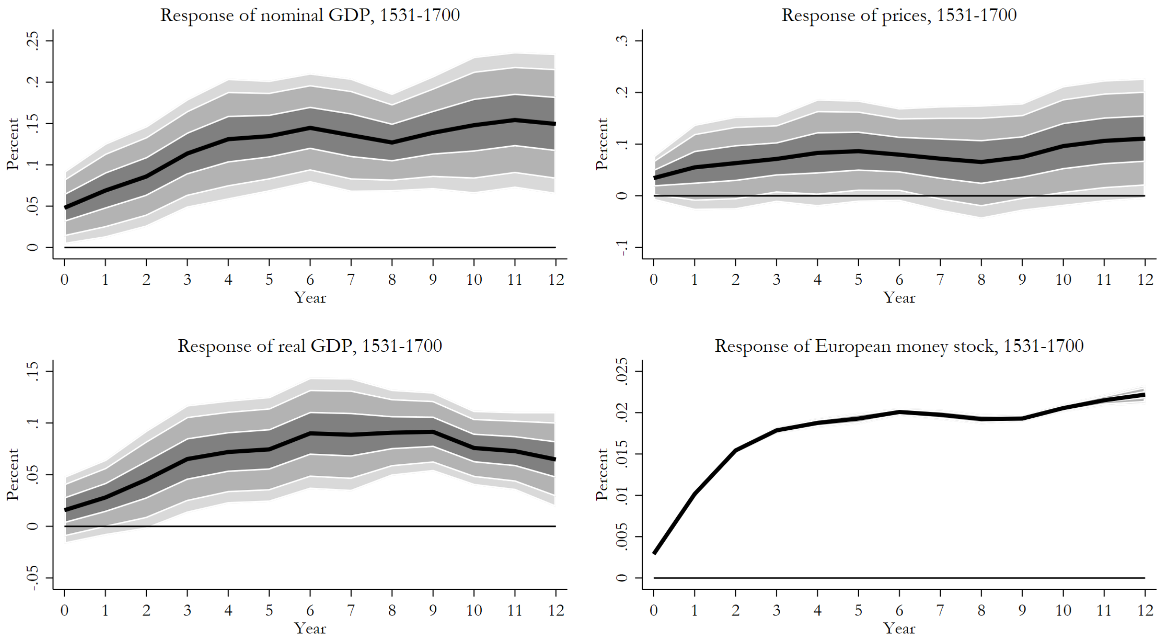

Figure A12: Robustness check: same specification as baseline, except 3 instead of 4 lags of dependent variables.

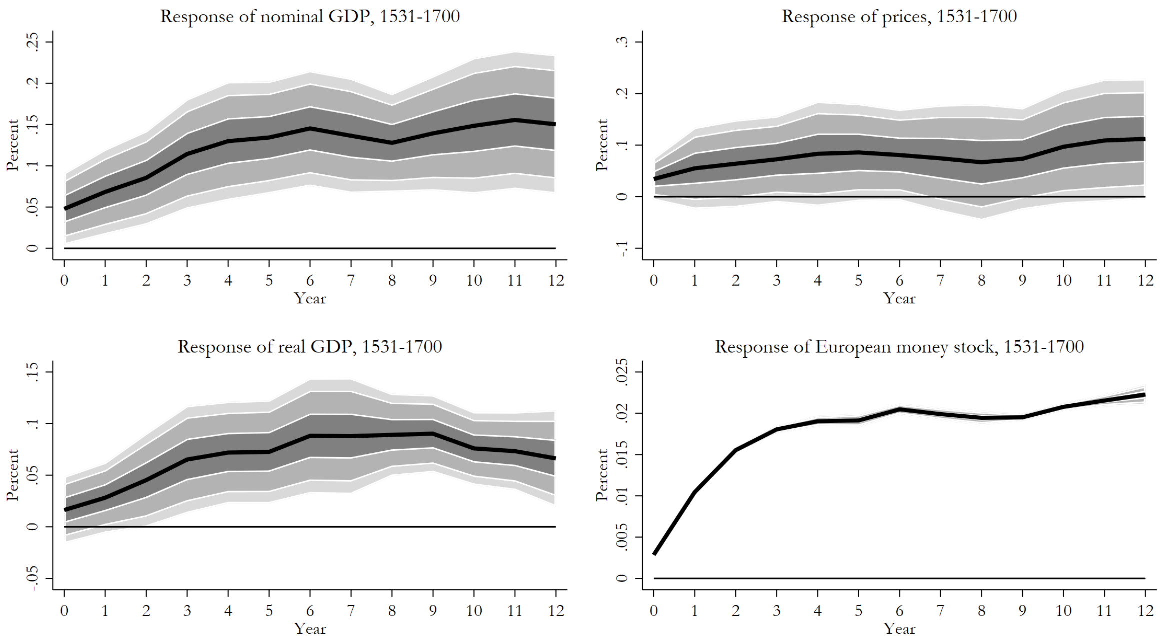

Figure A13: Robustness check: same specification as baseline, except 5 instead of 4 lags of dependent variables.

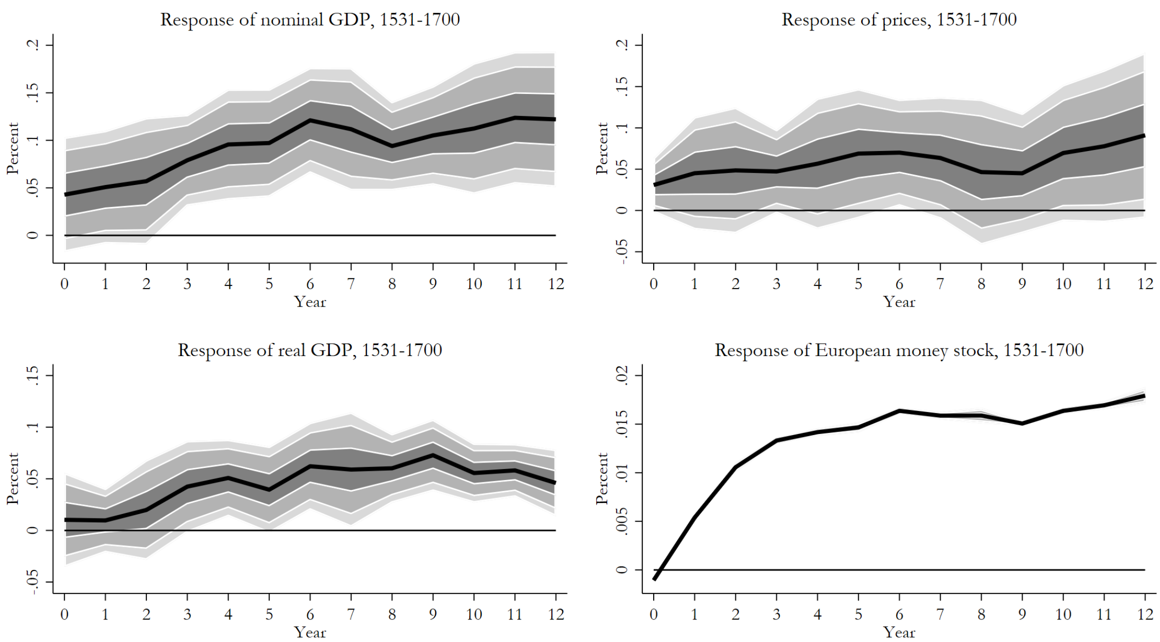

Figure A14: Robustness check: Same as baseline except one lagged shock added as a control variable.

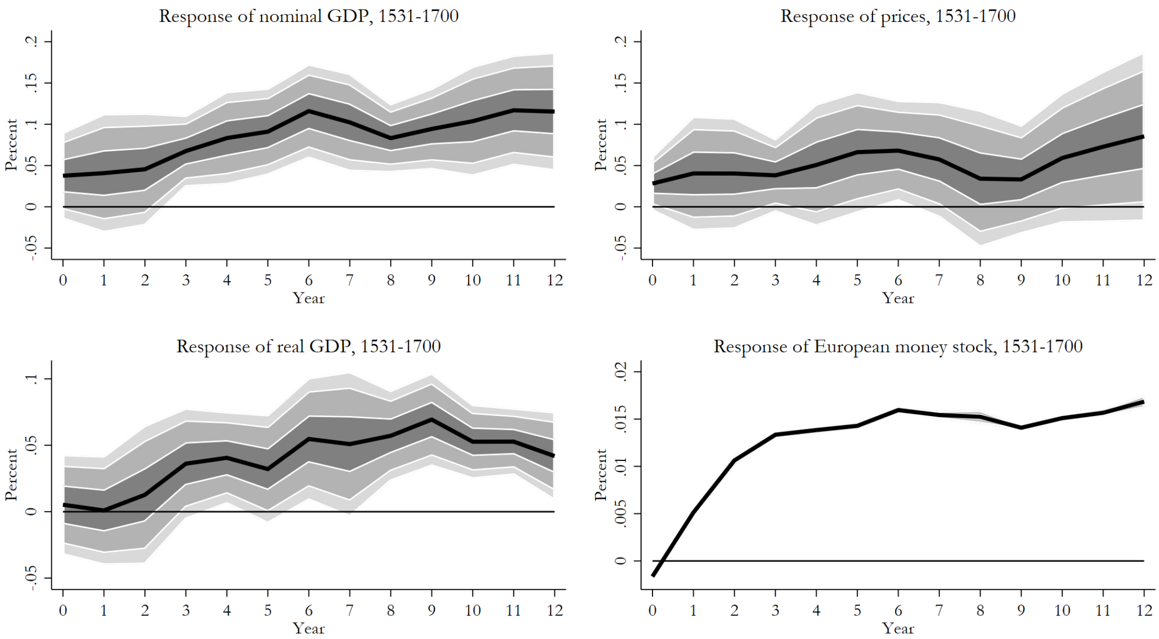

Figure A15: Robustness check: Same as baseline except two lagged shocks added as control variables.

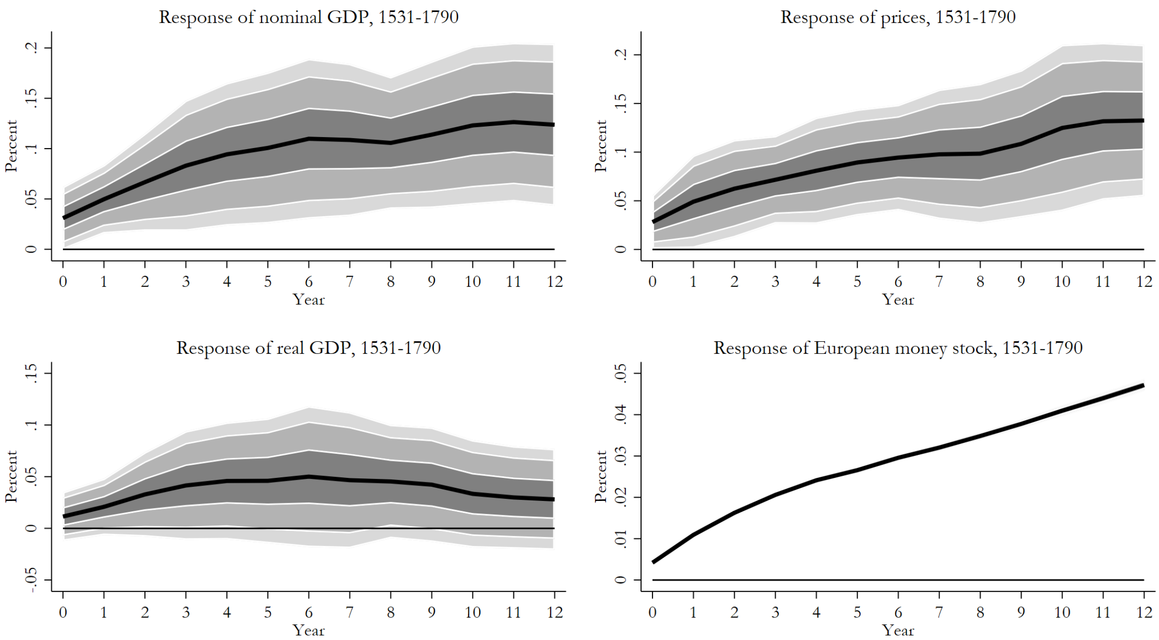

Figure A16: Robustness check: Same as baseline except for the 1531-1790 sample period.

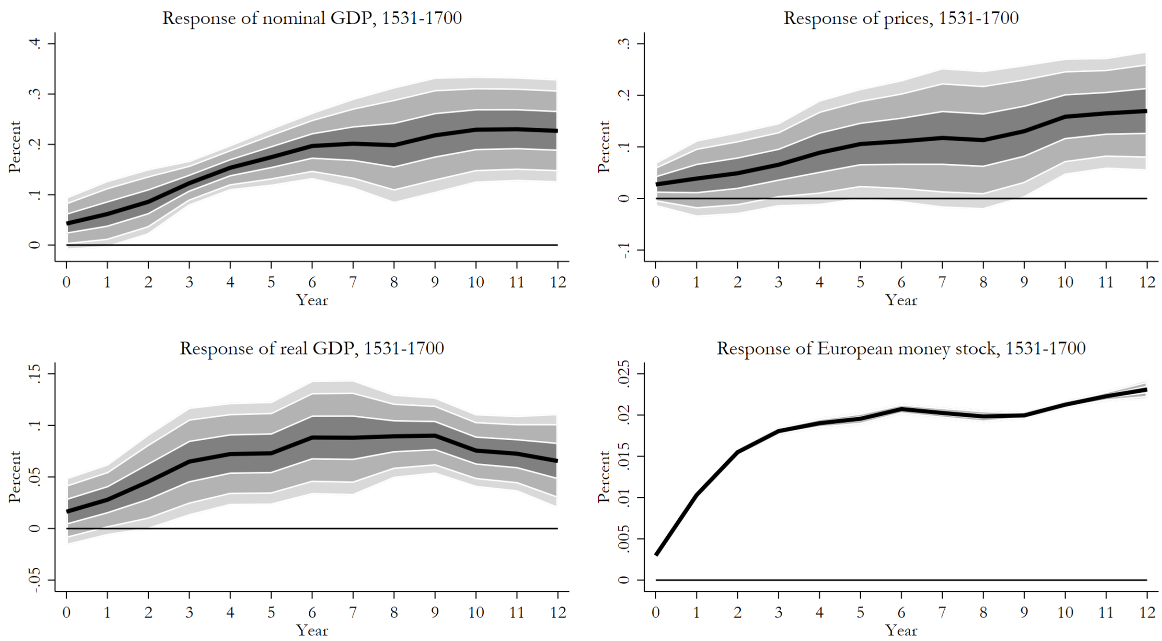

Figure A17: Robustness check: Same as baseline except prices and nominal GDP are in silver units.

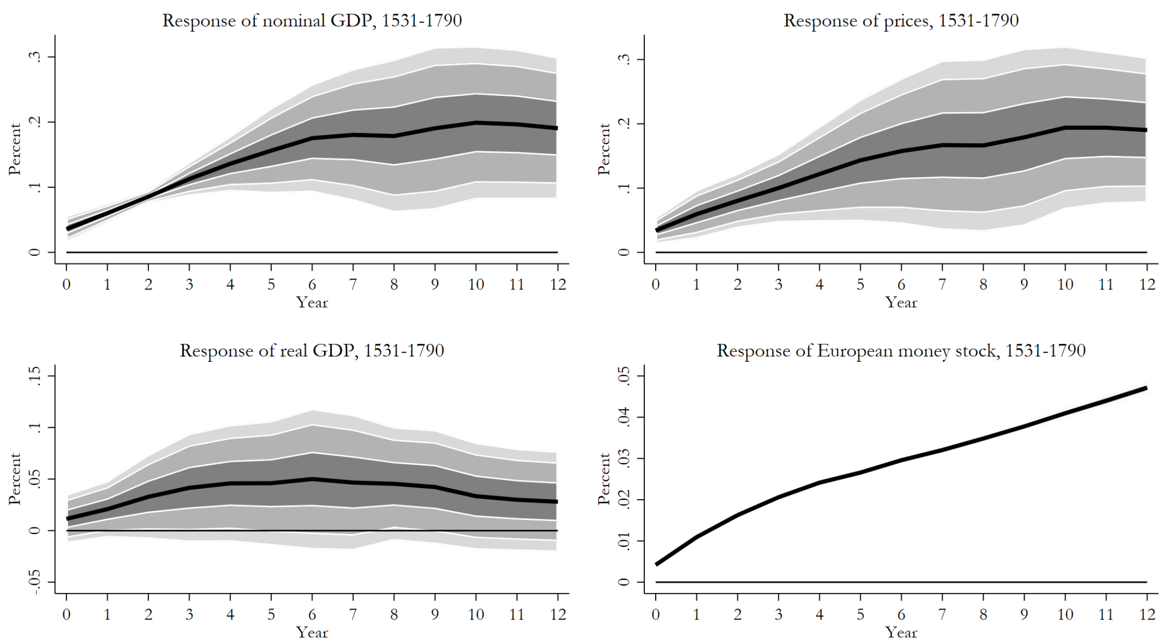

Figure A18: Robustness check: Same as baseline except prices and nominal GDP are in silver units and sample goes until 1790.

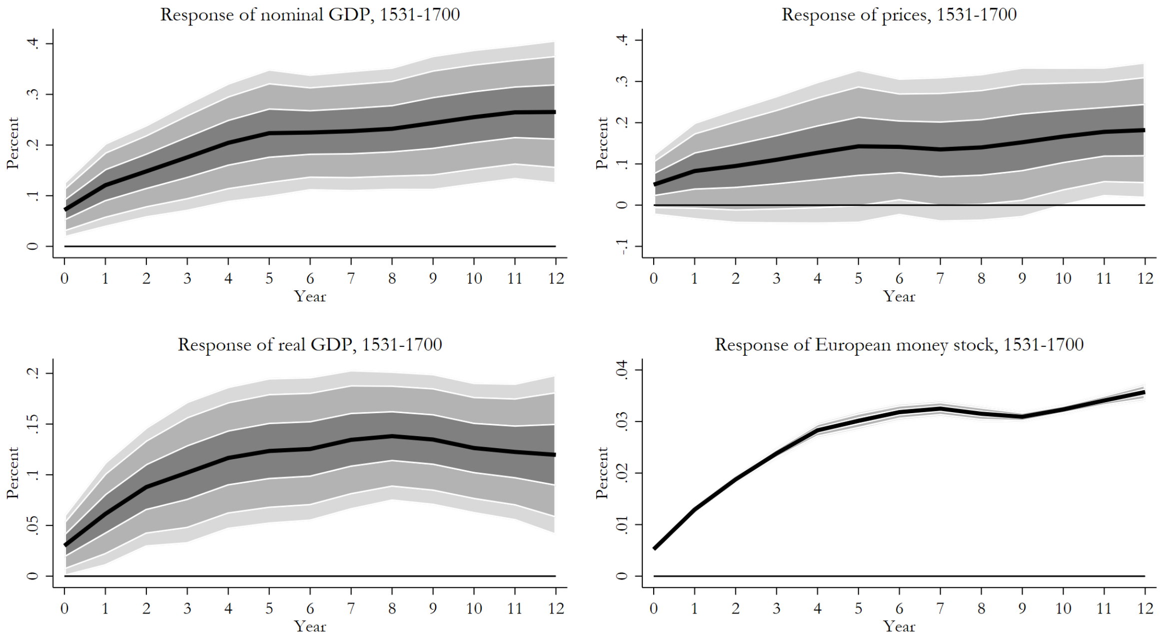

Figure A19: Robustness check: Same as baseline except no adjustment for shipwrecks done to the causal variable (production of precious metals in America).

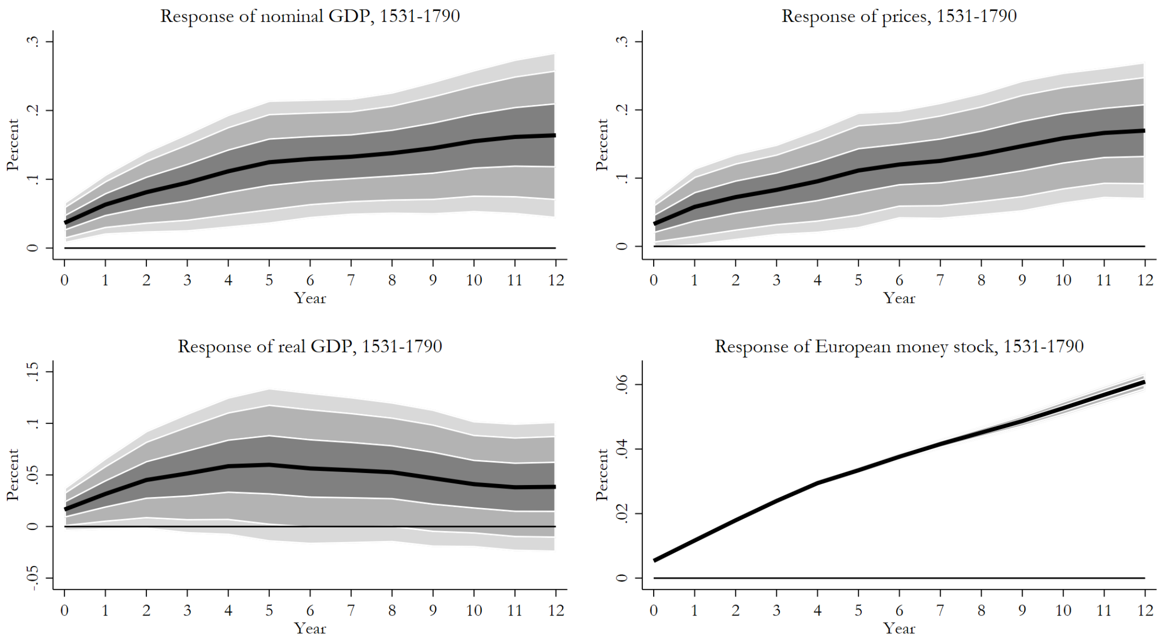

Figure A20: Robustness check: Same as baseline except no adjustment for shipwrecks done to the causal variable (production of precious metals in America), and using 1531-1790 as the sample period.

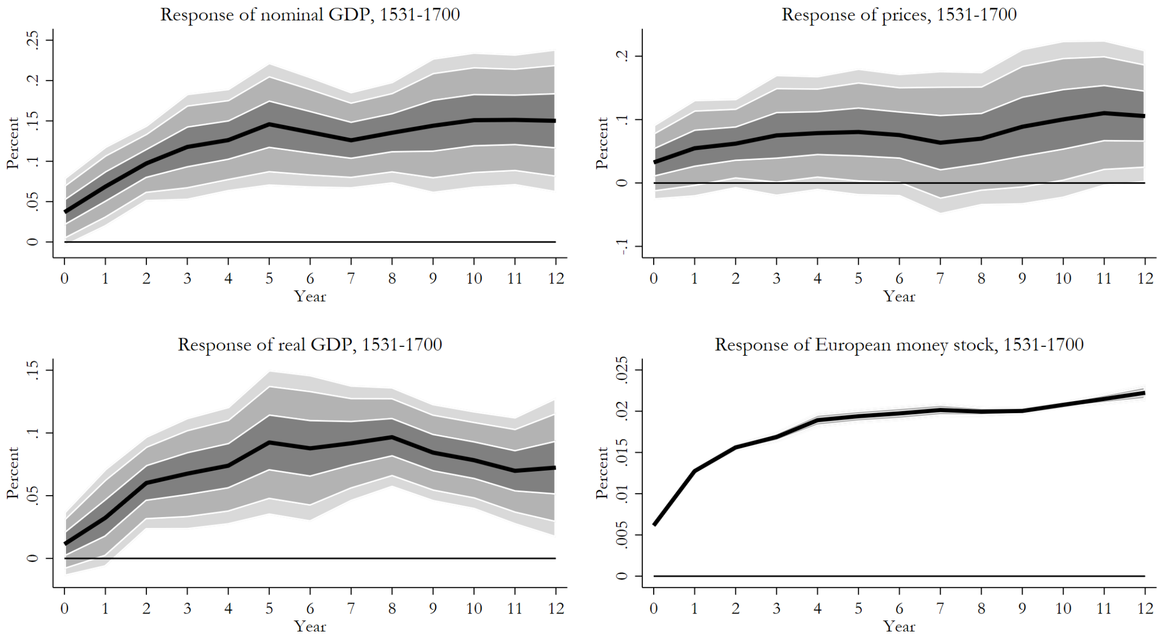

Figure A21: Robustness check: Same as baseline except adjustment for shipwrecks done to the shock variable in the same year rather than the following year.

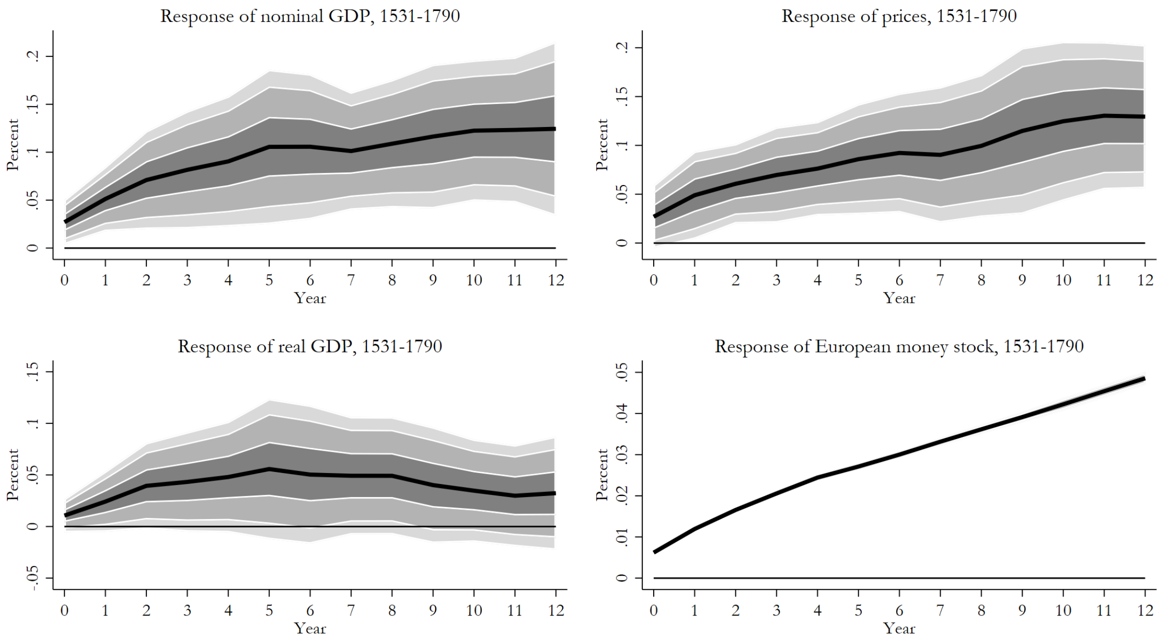

Figure A22: Robustness check: Same as baseline except adjustment for shipwrecks done to the shock variable in the same year rather than the following year, and using 1531-1790 as the sample period.

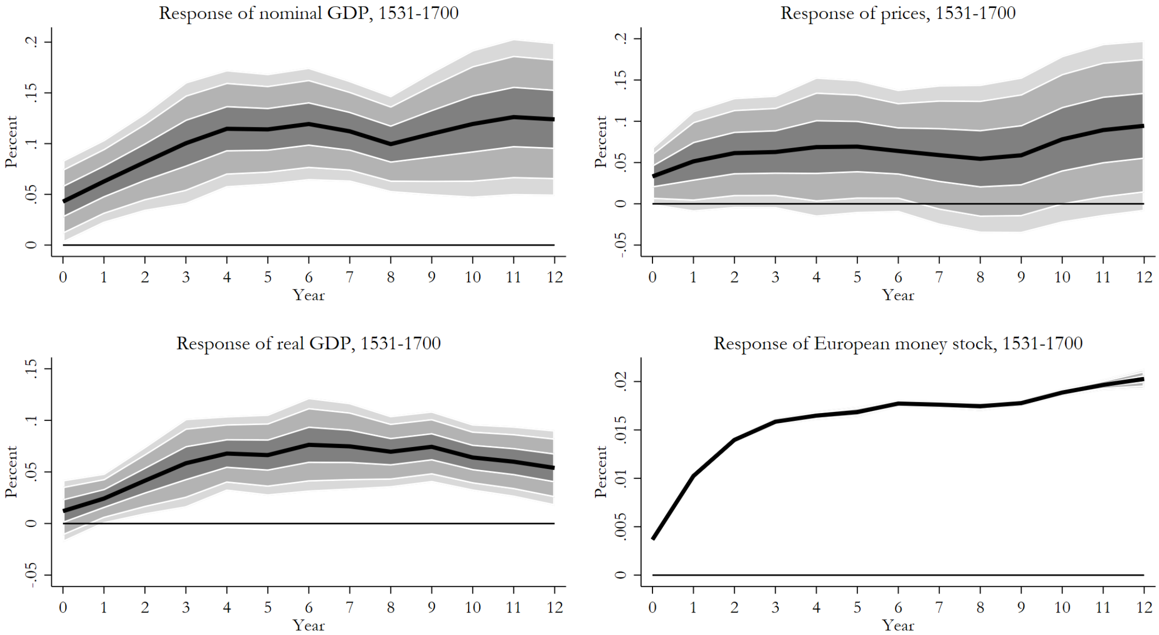

Figure A23: Robustness check: Same as baseline except adjustment for shipwrecks includes those caused by capture or combat.

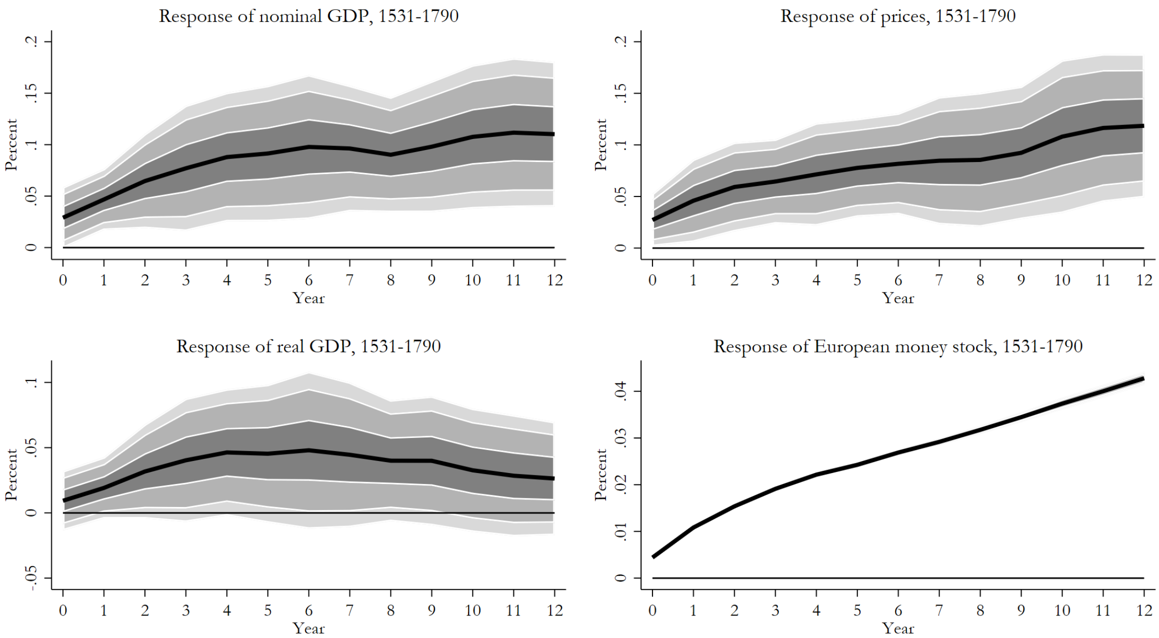

Figure A24: Robustness check: Same as baseline except adjustment for shipwrecks includes those caused by capture or combat, and using 1531-1790 as the sample period.

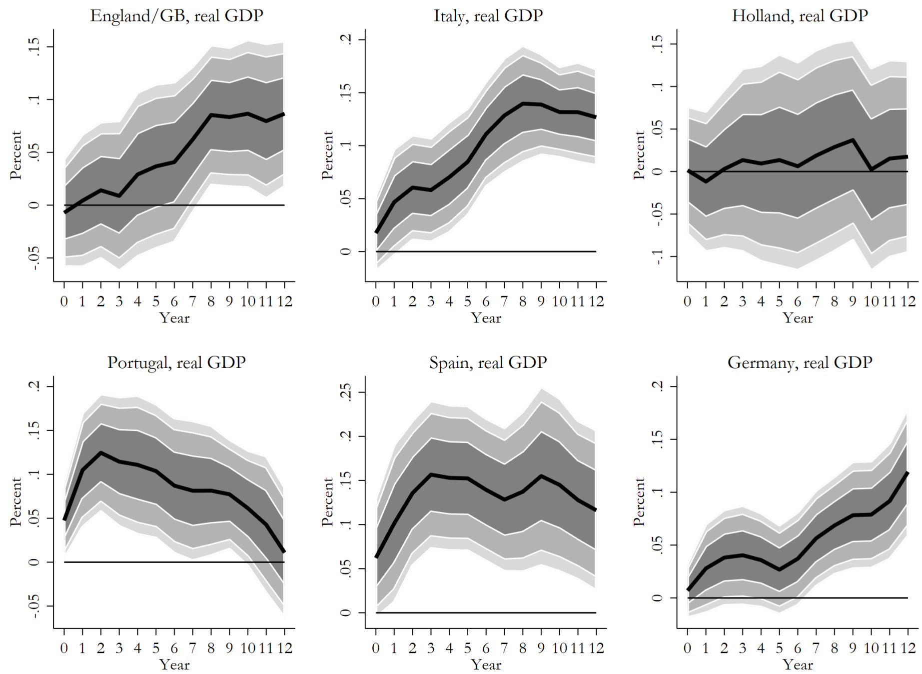

Figure A25: Robustness check: Same as baseline (for individual countries) without adjustments for shipwrecks.

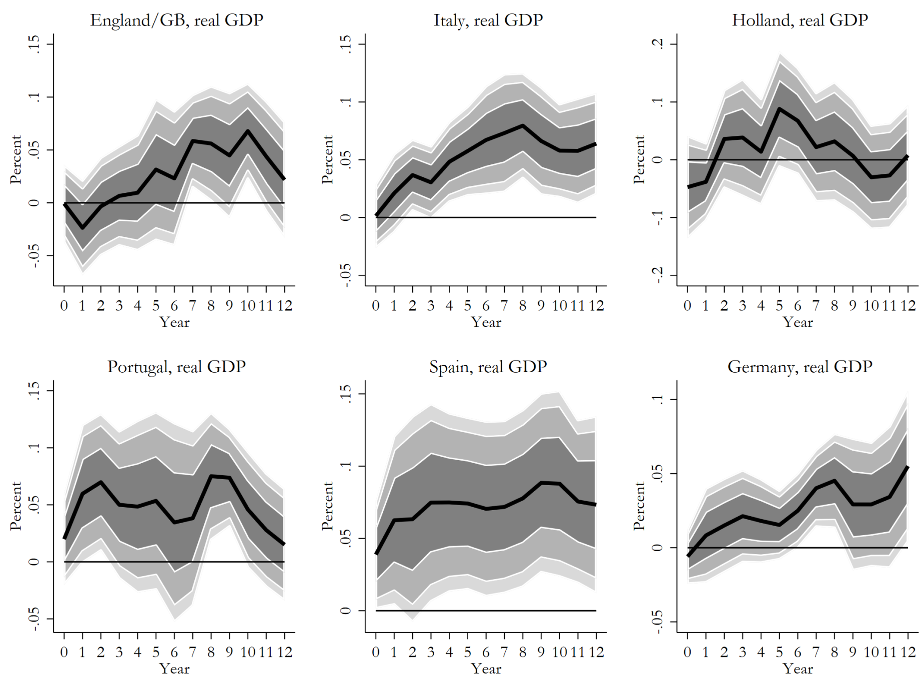

Figure A26: Robustness check: Same as baseline (for individual countries) except adjustment for shipwrecks done to the shock variable in the same year rather than the following year

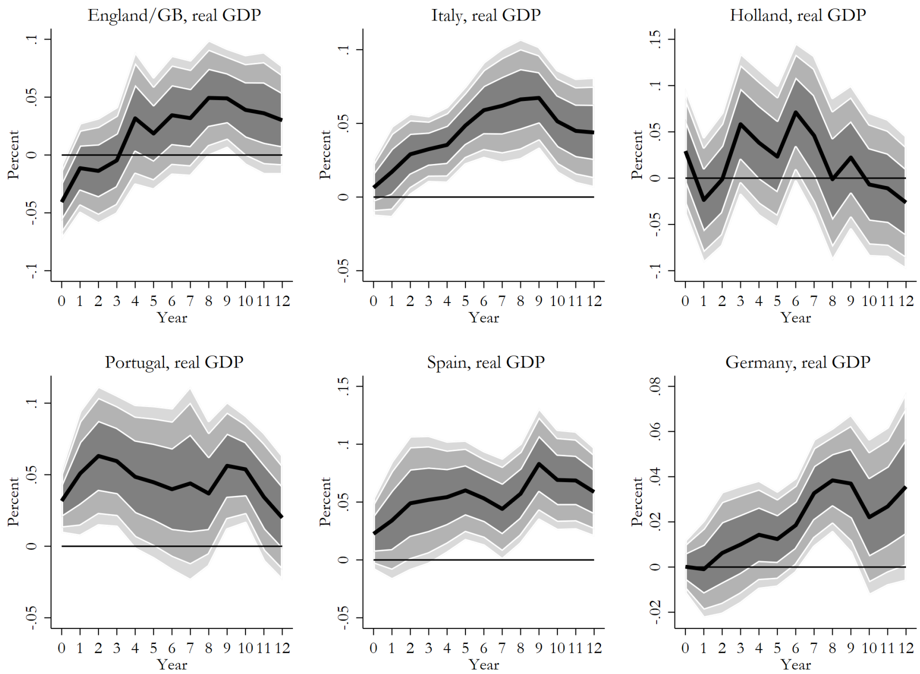

Figure A27: Robustness check: Same as baseline (for individual countries) except adjustment for shipwrecks includes those caused by capture or combat.

Dependent variable: money stock	(1) Baseline	(2) Lag 0	(3) Lag 2	(4) No Cott.	(5) 3-y average
metals production relative to stock	2.092***	2.320***	2.172***	2.017***	2.255***
	(0.503)	(0.534)	(0.546)	(0.542)	(0.511)
Cottington control	YES	YES	YES	NO	YES
Observations	142	142	142	142	142
First-stage F statistic (excluded instrument)	17.3	18.9	15.8	13.8	19.4

Table A1: First-stage results for England IV regression. Regressions follow the same specifications as outlined in table 3, except that no shipwrecks adjustments are made for the shock variable.

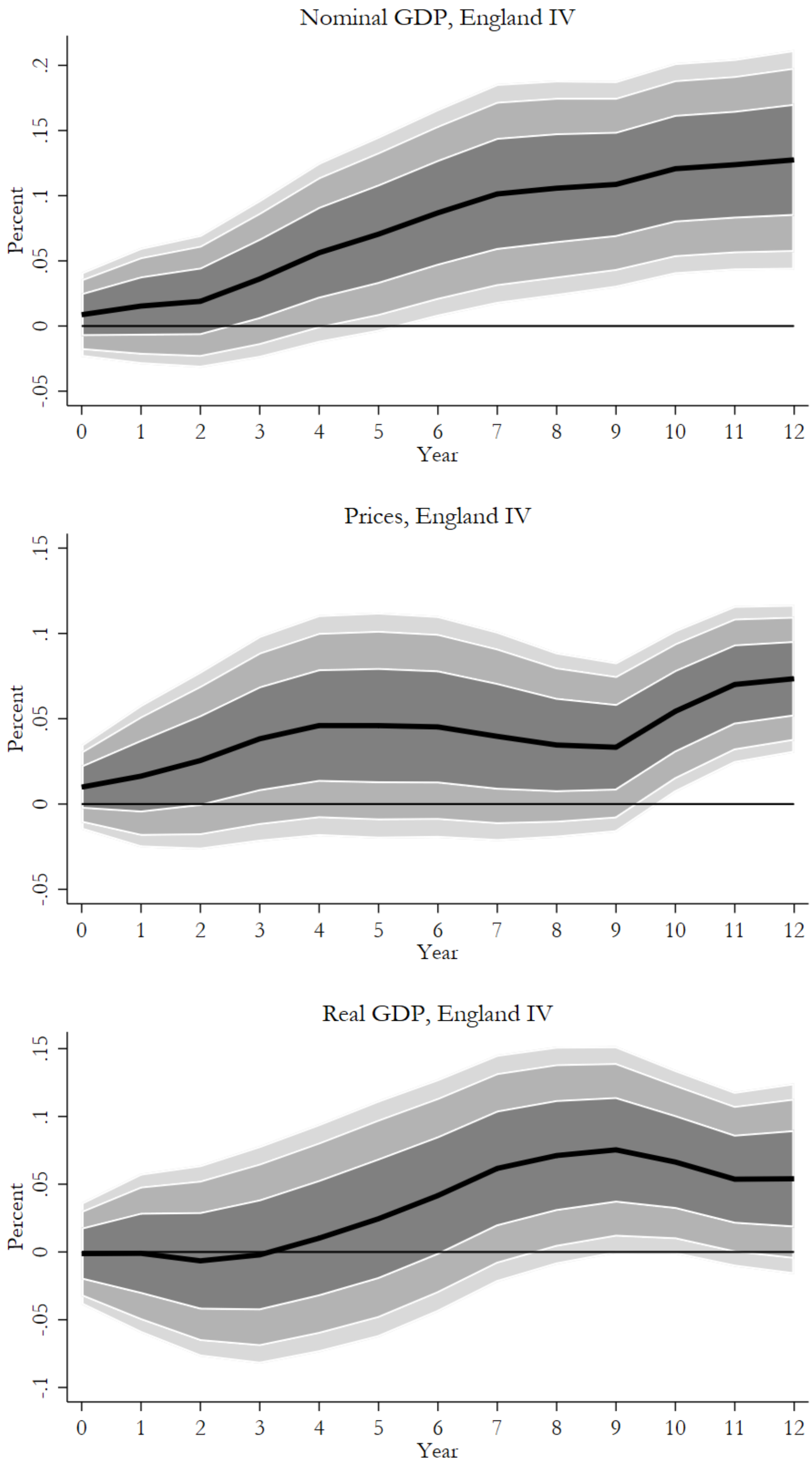

Figure A28: Impulse response of nominal GDP, the price level, and real GDP in England, to a contemporaneous 1% increase in mint output relative to coin stock (1559-1700), calculated using a two-stage IV local projection method. Same methodology as baseline in main text, except that no shipwrecks adjustments are made for the shock variable.

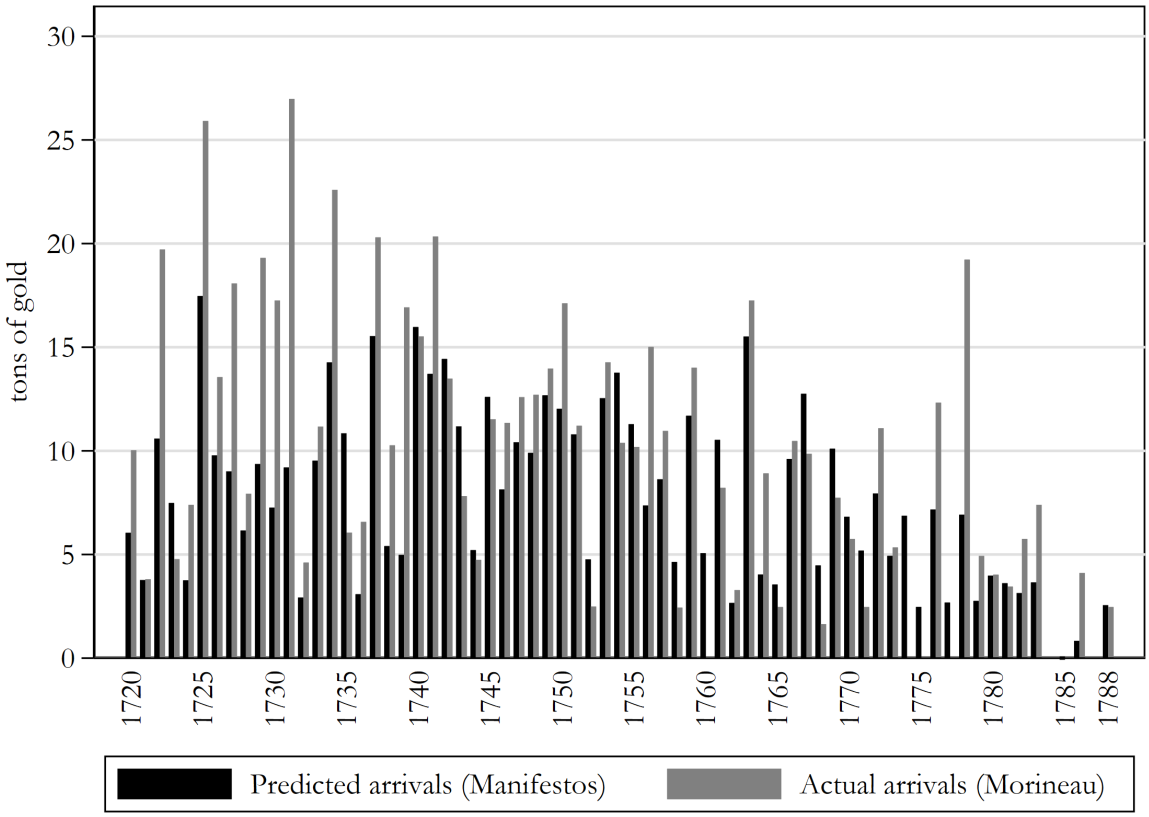

Figure A29: Dealing with endogenous formation of expectations: comparison of the informational upper bound (Manifestos) with the true arrivals (Morineau). Sources: Costa et al. (2013); Morineau (2009).

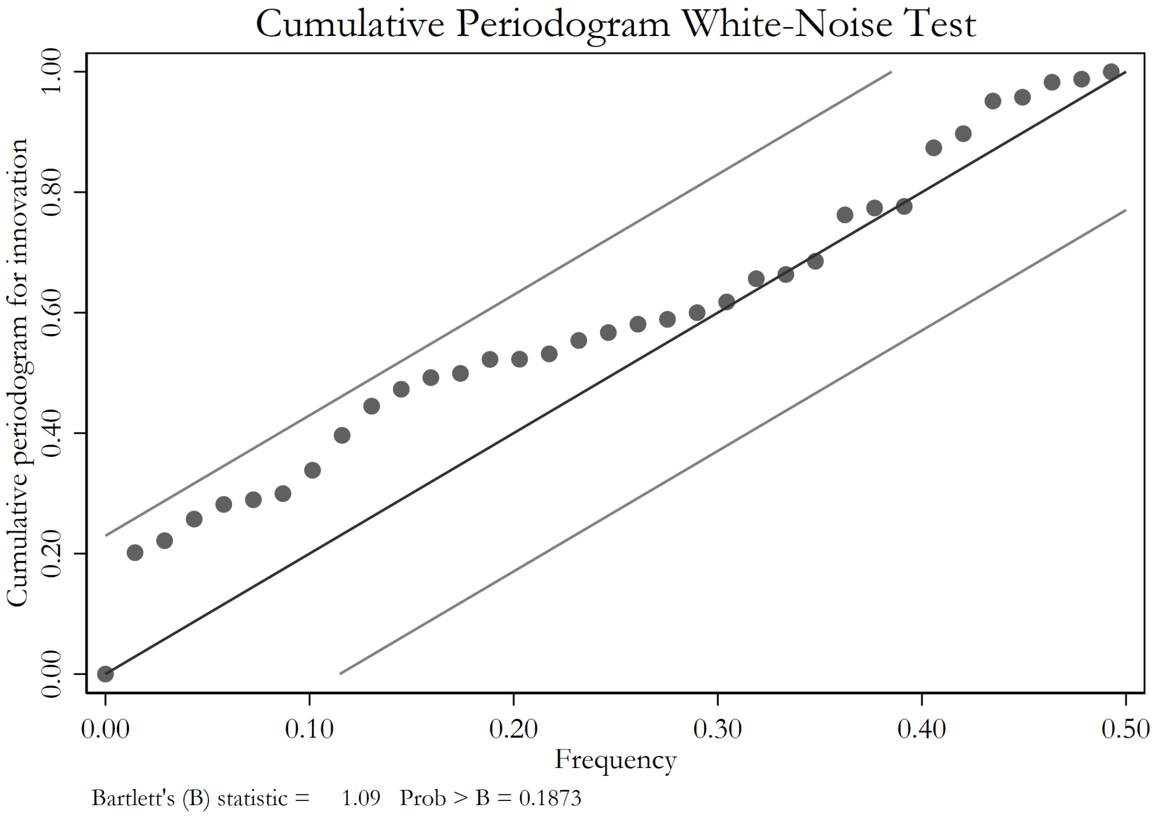

Figure A30: Dealing with endogenous formation of expectations: comparison of the informational upper bound (Manifestos) with the true arrivals (Morineau). Sources: Costa et al. (2013); Morineau (2009).

B. GDP reconstruction: sources and methods

Sources. The most common primary data sources for these studies are surviving account books of the landed estates formerly belonging to local government and royal administration, historical hospitals, prisons, charities, orphanages, universities, and institutions of the church, particularly monasteries and convents; see Palma (2020) for details. The sources are today in national and regional archives. The original institutions were purchasers (and sometimes sellers) of commodities and labor services, at market prices. It is hence possible to collect annual data on wages, land returns, and prices. Capital returns are usually harder to obtain, though (from different sources) it is often possible to find interest rates of different maturities, and corresponding to both private and public borrowing. The account books typically display the date of the transaction, the gross and unit value of the commodity, the unit of measurement employed, the quality of the product (e.g. coarse or fine paper, mutton, pork or beef) and particular features of the transaction. By collecting prices from the account books, it is possible to construct a price index that allows for inflation-adjusted values to be known. For most of the GDP reconstruction studies the data is annual, and while occasionally interpolations have been used, this has been the exception rather than the norm.

Reconstruction methods. Output-side reconstruction is standard and explained in the main text. As for the demand-based method, domestic consumption of agricultural products is assumed to be equal to agricultural production (the external sector is adjusted for, when necessary). Values are deflated to arrive at constant prices of a given year. The basic input across all demand-side studies is real wages. Plenty of data exists with which to construct nominal wage series for many occupations, for both skilled and unskilled workers, and for both urban and rural occupations. A source of difficulty is that historical wages are most frequently registered as day wages. This means that assumptions about work time are needed to calculate annual income. Real wages are determined by dividing the nominal wage by a Consumer Price Index defined by Allen (2001), sometimes adjusted for local consumption patterns, keeping calories and protein content approximately constant (e.g. olive oil being part of the basket in Southern Europe instead of butter, and wine instead of beer).

Once an index for real wages is obtained, a consumption-based demand method is applied to arrive at an estimate for agricultural production (de Jong and Palma, 2018). The next step aims to arrive at an index for GDP. Two alternative methodologies have been used. The first uses an inter-sectorial productivity gap calculated at a given moment T, when it is known. Year T should take place before modern economic growth with significant structural transformation and changes in relative prices took place. This is then assumed to be a constant, extrapolated back in time, and combined with the relative share of labor and land income at any point in time in order to calculate per capita GDP for previous periods (e.g. Palma and Reis (2019)). A second methodology is a short-cut method that uses a regression which that has as a main input the size of the urban sector (Álvarez-Nogal and Prados de la Escosura, 2013; Malanima, 2011). As Palma and Reis (2019, p.498) show, these methods lead to similar results. With these real volume indices at hand, real GDP per capita levels for any given year can be obtained backwards from the first available solid benchmark at constant prices (usually 1820 or 1850). Note that quantities are measured directly in the supply-side studies. The others rely on data such as urbanization rates or on supply-side benchmarks combined with annual production data for certain staple crops to estimate quantities, notably the number of days worked per year (see, for example, the procedure used by Palma and Reis (2019, pp.490-492)).

C. Dealing with potential covariate mismeasurement

If precious metals production was seriously mismeasured, this should considerably bias my coefficients downwards in absolute terms.[2] One potential source of mismeasurement could be that precious metals were smuggled and thus do not show up in official records. The fact that I find strong and significant results suggests the true effect was likely to be even larger. In order to account for the possibility of smuggling, I now consider data on the use of mercury, a fundamental input for the production of silver. As discussed in the main text, technological change and variable mining productivities meant that the relation between mercury usage and production was not linear. Still, the correlation was usually tight (Figure A31), which suggests production estimates from fiscal sources are not out of line with reality, as also argued by several historians, e.g. Bakewell (1971, p.186).

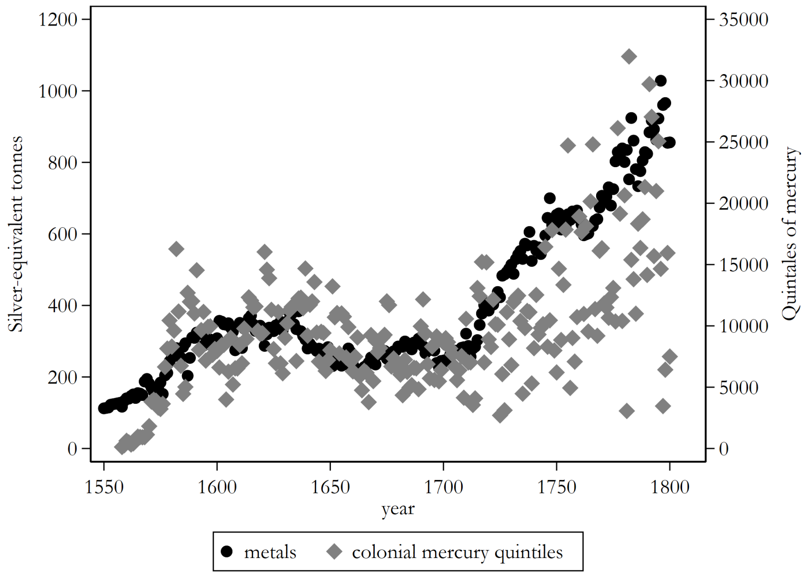

Figure A31: Production of precious metals and mercury usage in Quintales (1 quintal = 100lbs), 1558-1790. As complied from a wide variety of primary and secondary sources and made available by Richard Gardner at http://www.insidemydesk.com/ (last accessed January 22nd, 2015). Sources: Gardner (1988); TePaske (2010).

As the figure suggests, after about 1700 the correlation breaks down to some extent; while the trends continue to be similar, there is a level effect downwards for mercury usage. There are two reasons for this. First, the eighteenth century was the age of gold, and there is evidence that mercury was particularly useful for silver, not gold (Figure A32 shows that some of the divergence can be accounted for if gold is excluded). But second, the direction of the breakdown matters. If, after 1700, mercury supply had been well above silver production levels, then this might be a sign of increased smuggling after that time. The fact that it was below instead suggests that it corresponds to higher TFP in the mining production function. Indeed, as the figure also suggests, the change corresponds to a level effect only, as the trends continue to

[2]As with classical measurement error, there should be attenuation bias.

be similar. In sum, data on mercury utilization suggest that tax-avoidance was not an issue of first-order importance, so annual volumes of precious metals production are approximately right. This is perhaps not surprising since as mentioned in the text, several monitoring mechanisms were in place and there were severed penalties for tax avoidance including death (Hamilton, 1934, p.17).

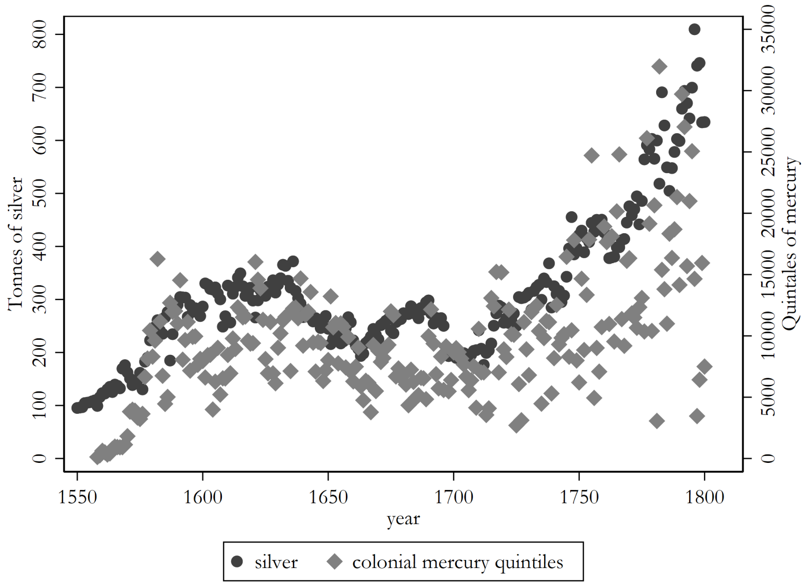

Figure A32: Production of silver and mercury usage, in Quintales (1 quintal = 100lbs), 1558-1790. As complied from a wide variety of primary and secondary sources and made available by Richard Gardner at http://www.insidemydesk.com/ (last accessed January 22nd, 2015). Sources: Gardner (1988); TePaske (2010).

Smuggling is also unlikely to have much affected the *livros de manifestos de 1%* mentioned in the text, because it made sense to transport precious metals in bulk and in protected convoys. Scale economies, coordination problems, and strategic security considerations ensured that, if available, official convoy transportation was the optimal choice for most merchants – even if some hidden quantities could still be present onboard. Even in the case of gold, which was easier to smuggle than silver because of its higher value-to-volume ratio, it usually made sense to transport it officially. In the case of Brazilian gold after 1720, for example, the state charged a rate of only 1% for the transportation of gold across the Atlantic (Costa et al., 2013).

D. Liquidity or wealth effects? Spain as a case-study

I now focus on Spain as a case study. Spain was the main first-wave receiver of the metals (and the only receiver until about 1700) but even for this case, the observed effects operate mainly through additional liquidity rather than being the result of an endowment or wealth effect. One might have guessed that the early effects in Spain and Portugal, and their magnitude relative to the later and sometimes weaker effects in other countries is explained by wealth effects: being the colonizers, Spain and Portugal became richer as a result of the precious metal production, at least in an initial stage.[3] I now show that the wealth channel was in fact relatively small even for Spain, which in turn implies that elsewhere in Europe, the effects were mainly driven by increased liquidity.

In line with my argument that what explains my findings are mainly liquidity rather than wealth effects, I now show that the ratio of silver production as a share of Spain's wealth was small. American silver of precious metals was worth around 6% of Spain's GDP in most years, and always below 10%, as Figure A33 shows. For modern economies, wealth is about 5 times GDP, and it was even larger for past economies – it was 7 for the UK around 1700 (Piketty and Zucman, 2014). This means that the shock was always a small part of Spain's wealth. In fact, since not all of the silver arrived to Europe, and since some of the gold belonged to Portugal, the Spanish silver inflow-to-GDP ratio ranges from 0.75% to 6.5%. Assuming the previously mentioned pre-industrial wealth-to-GDP ratio of 7, this implies that Spanish annual silver inflows ranged only between 0.1% and 1% of the Spanish wealth levels (and only slightly more if accouting for gold). It seems hard to believe that such a small shock to Spain's wealth would generate by itself the large effects throughout Europe that I find.

Figure A33 refers to Spain since it was the main first-wave receiver of the metals. Spain was the only producer in the 16th and 17th centuries, and while Portugal produced important quantities of gold in Brazil in the eighteenth century, it did not produce silver.[4] For the specific case of the Lisbon market during the Brazilian gold boom of the eighteenth century, a recent study builds a small dataset of market interest rates and concludes that "the liquidity channel dominated over the endowment channel, which explains the downward trend in interest rates" (Costa et al., 2017).

[3]Notice that the existence of effects at the horizons discussed here by no means exclude the possibility that Spain was a victim of Dutch disease or institutional resource curse as a consequence of these inflows. These would, however, have operated at a longer horizons that are beyond the scope and methods of this paper.

[4]I focus on silver because most of the gold production in the eighteenth century was in Brazil and hence belonged to Portugal, and earlier gold production was marginal, as shown in Figure 2. The graph shows an upper bound to the value of what arrived to Europe because much of the production never reached Spain, going instead directly to Asia via the Pacific, or staying in the Americas. As much as 50% of total silver production went to Asia (Irigoin, 2009; Palma and Silva, 2016), though this was shared between the Pacific route or via Europe first, followed by the Levant, Baltic and Cape routes. The fact that not all production ended up in Europe is not a problem for my main results since I only use production as a source of exogenous variation of European money supplies; I do not need the first stage – whether explicit in the case of England or implicit in the other cases – to explain all the variation in European money supply.

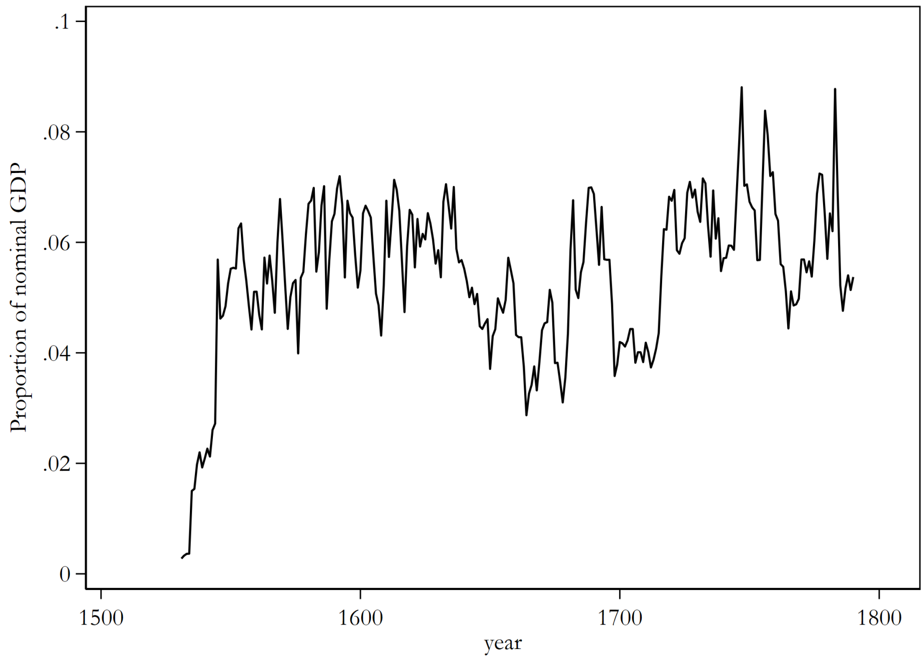

Figure A33: American silver production divided by Spain's nominal GDP (both in real de vellón). Sources: Álvarez-Nogal and Prados de la Escosura (2013, 2017); TePaske (2010)