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Spending a Windfall: American Precious Metals and Euro-Asian Trade 1531-1810

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Abstract

During the early modern period, Asia ran a large current account surplus with Europe. We show that the critical factor to stimulate Euro-Asian trade was not the new trading routes to Asia, but the European access to American precious metals. We use a dynamic general equilibrium model to reproduce historical data and calculate alternative scenarios. We find that European imports of Asian goods were up to thirteen times higher than they would have been without new routes and without precious metals. The effect of American precious metals is six times larger than that of the discoveries of new trading routes.

JEL codes: E40, F40, N10.

Keywords: Early modern trade, monetary injections, dynamic general equilibrium models with heterogeneous agents, real effects of money.

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1 Introduction

> European demand for eastern goods was certainly high, but Asian demand for bullion and coin was so great that the rise of European trade with the east should be seen primarily as a consequence not of trade routes to the east but of the discovery of America (Harley 2004, p. 179)

The large and persistent current account deficit of Western countries vis-a-vis Asian nations is not new. In the early modern (1500-1800) period, Europe also ran a significant current account deficit with Asia, which lasted over 300 years. In this paper, we use a dynamic general equilibrium model to show that discoveries of precious metals in America can explain the volume of international trade between Europe and Asia during that time. We show that the discoveries of precious metals in America in the early modern period were fundamental for the increase in imports by European consumers of Asian goods. This is contrary to the idea that the decrease in trading costs after the discoveries of new trading routes in the period was the most important factor.

We use data on the discovery of precious metals in America to simulate paths for the historical and counterfactual scenarios. With the discoveries of precious metals, European purchases of Asian goods are up to thirteen times those of the baseline counterfactual scenario. This effect is over six times larger than that which can be attributed to the discovery of new overseas trade routes to Asia. No Asian preference for hoarding is required to explain these patterns, as the conventional historical explanation holds. Our conclusions support a historical hypothesis which suggests that American precious metals are key to understanding Euro-Asian early modern trade (DeVries 2003).

In an effort to understand the rise of Europe, much recent research has emphasized the importance of new opportunities initiated with the age of discoveries. Researchers have stressed the importance of trade in precious commodities such as pepper and other spices, profits from trade in association with political economy, and the importance of London's trade-driven growth in driving up English real wages (Williamson and O'Rourke 2009, Acemoglu, Johnson and Robinson 2005, Allen 2009). We focus on evaluating the role of American precious metals in Euro-Asian trade.[1]

Europe and its colonies paid 90% of their imports from China during the early modern era using silver (Pomeranz 2001, p. 159), a pattern which was not too different from that of trade with India (Steensgaard 1995, Chaudhuri 1968). It would have been difficult for European traders to position themselves in Asian markets without access to American precious metals. While European consumers were interested in purchasing Asian luxuries, the reciprocal demand did not exist. Asians were only interested in precious metals.[2] If Europe did not have access to bullion from America during the early modern era, there is no obvious substitute which could have been used. Payment by means of debts of long maturities was not possible as no credible enforcement

[1] It has been argued that New World precious metals contributed to the rise of Western Europe towards modern economic growth (Pomeranz 2001, Frank 1998). But it is impossible to assess the importance of this cause without having a plausible quantitative estimate for the question: what would have happened if there was no American treasure?

[2] We discuss below why this may have been so. While most historians have simply assumed Asian consumers were not interested in European goods, in our model such trade pattern emerges endogenously during the early modern era, despite the assumption of symmetrical preferences for European and Asian consumers.

mechanism was available, and no predictable horizon existed for the reversal of equilibrium trade flows. Indeed, "the whole commercial system (...) in the Indies would have come to a standstill without the prompt supply of ready money" (Chaudhuri 1963, p. 29).[3] When this deficit finally ended, it did so largely by force. In the case of India, with the takeover of the Mughal empire by Britain. In the case of China, with the Opium wars. It is unlikely that much earlier in time European powers could pack the necessary military means to successfully implement these actions.

Contemporaries were well aware that Asia absorbed much of the precious metals that Europeans brought from the New World. For instance, DeVries (2003, p. 94) cites a merchant wrote in 1621 that the world's silver flocks to China "where it remains as if at its natural center". According to DeVries, "India also attracted silver (and gold), yet in both Asian centers the demand seemed to be insatiable." But while Asians did not show much interest in purchasing European goods the opposite was true for Europe. Early modern Euro-Asian trade brought to Europe exciting exotic goods such as pepper, spices, silk, tea, porcelain, and lacquered furniture. These were the iphones of the time. These good induced extra work, specialization and market activity, and, as time went by, were increasingly consumed by people from all social classes (McCants 2007, 2008, Pomeranz 2001, p. 273, DeVries 2008, Voth 2001, Hersh and Voth 2009). Trade in Asian goods such as Chinese porcelain and Indian textiles shaped European tastes and were a prerequisite to the subsequent British industrialization effort.[4]

The traditional and still currently accepted explanation by historians for the imbalance of early modern Euro-Asian trade relies on cultural factors. Earl J. Hamilton, for instance, states that "[f]or some inexplicable reason Orientals have always had *a penchant for hoarding treasure* (...) even in response to a protracted inflow of specie, Oriental prices, unlike those of the Western World, did not rise sufficiently to induce a counter flow" (Hamilton 1929, p. 347, our emphasis). In turn, Keynes (2013) wrote about India that "[t]he oriental habit of hoarding or transforming into jewelry vast amounts of precious metals appears to be a chronic one." This view has not changed in recent decades (see for instance Kindleberger 1990, or Maddison 2007, p. 312). By contrast, our explanation for the patterns of Euro-Asian trade in the early modern period does not rely on different preferences for Asians. Instead, our explanation emerges as a natural consequence of rational agents taking decisions in a dynamic general equilibrium context.

In order to understand the role of American precious metals in promoting Euro-Asian trade,

[3] During the early modern period (to a first order approximation) for any given year the value of imports and exports must match. Hence when we refer to "current account deficit" for this period we define precious metals as money, as opposed to goods.

[4] The French Huguenot Bernard Palissy famously tried, for sixteen years, to reproduce the Chinese porcelain fabrication method—and failed. The basic technique was eventually learned in Europe, though the fabrication method was never as perfect as that of China. By the mid-eighteenth century all major European countries had or were about to have porcelain factories. A major interest in *Chinoiserie* (which was not limited to porcelain, but also architecture, landscape gardening, lacquerware furniture, and decorative arts) developed. Maxine Berg consequently argues that "[T]he link between East and West contributed to the wider expansion of consumption and industry in Europe which accompanied and followed it. (...) The global trade in [Asian luxuries] stimulated a program of product innovation in Europe in attempts to 'imitate' and to make indigenous those products that were at the time manufactured in the advanced consumer societies of China and India" (Berg 2004, p. 86). She concludes then that "Imports of manufactured luxury and fashion goods prompted a process of product innovation leading to industrialization" (Berg 2004, p. 141). See also Berg (2007).

we start by reviewing evidence on the size and effects of the monetary injections caused by the higher availability of precious metals. To understand trade flows as equilibrium phenomena, we review the relative size and development of Asia versus Europe during this period.[5] While world money stocks for the early modern period are unknown, production of specie is a good proxy to estimate the magnitude of the monetary injections, as bullion was the main input in the production of money. We estimate Europe's stock of precious metals at some key periods during the early modern period using Europe's initial stock measured in tonnes of silver, and data on the discoveries of precious metals in America. We then estimate a dynamic general equilibrium model which makes transparent that monetary flows were an equilibrium phenomena. In our model, there are two frictions. The first is that money is necessary to conduct transactions. The second is that there are transaction costs to international trade, which represent both transportation and agency costs. The aim is to reproduce how Euro-Asian trade responded to the discovery of new trading routes and to the monetary shocks of the early modern period. The model can be used to explain observed history and to predict the counterfactual: what would have happened if no precious metals were available in America? and what mattered the most, was it American precious metals or the new overseas trade routes to Asia?

A small amount of Euro-Asian trade was already taking place in the middle ages through overland routes, but trade grew exponentially during the early modern period. We emphasize the role of American precious metals as a cause to explain the observed growth in trade. However, alternative factors have been pointed out. DeVries (2003, p. 38) raises three possibilities. First, was the trade boom induced by "new opportunities for arbitrage in regional differences in the purchasing power of silver"? (this is the factor we emphasize). Second, "was it the result of a major reduction of transaction costs, as new technologies and commercial organization lowered the cost of acquiring and shipping goods (...) [or] because political barriers to trade fell in the face of the military power of the trading companies"? Third, perhaps Euro-Asian trade grew due to rising incomes in Europe raising demand for imports from Asia? The possibilities raised by DeVries are evidently not mutually exclusive. But how should we think about their relative importance? Using our model, we are able to decompose which part of the observed increase in early modern Euro-Asian trade can be attributed to the discoveries of precious metals, the decrease in transaction costs, or the increase of income levels in Europe. The model is hence useful to disentangle the effects.[6]

We find that the discoveries of precious metals were by far the most important factor. The discovery of new overseas routes to Asia[7] (the Cape route and the Pacific route) would have at doubled Euro-Asian trade in the absence of American precious metals relative to medieval trade levels. On the other hand, European access to American precious metals without the discovery of

[5] In discussing the macroeconomic consequences which resulted from this episode, we wish to shift the historical debate from effects of money and inflation on the European economy—sometimes discussed as if it was a closed economy—to worldwide effects which operated through monetary transmission.

[6] Disentangling the effects through reliance on historical evidence alone is complicated by the fact that these events happened at roughly the same time. The Portuguese first arrived to China in 1513, just as the Spanish were beginning to extract silver and gold from America.

[7] By "discovery of new routes" we simply mean the lower early modern transport and agency costs of trading with Asia. Hence, we are here including now only the discovery of the routes proper, but also the associated technical and organizational change.

new routes imply that Euro-Asian trade was over six times what it would have been without them. Under access to both new routes and American precious metals, Euro-Asian trade increased to thirteen times what it would have otherwise been.[8]

2 Historical background

2.1 Precious metals and monetary injections

Paper money become prevalent in Europe only in the nineteenth century. In England, as late as 1790 the monetary base was composed of £44 million of commodity-based coin but only £12 million in notes. Inland bills of exchange and other instruments which were functionally money were also used, but they had a small share of the monetary base (Capie 2004, Palma 2016d).[9] Until the rise of paper money, monetary authorities only had two ways of increasing the monetary base, which was essentially coin. The first was to devaluate it, by decreasing the precious metal content of the coins in circulation. This policy was constrained by competition with foreign mints and political constraints. Another way was to have increased access to precious metals, the critical input in the production of specie.[10] Individuals could obtain this either by direct production (mining) or through a secondary market. Monetary policy was conducted by means of the monetary authority setting the mint price at which private agents could coin currency from bullion, after payment of a mint costs and a seigniorage fee. Prior to the age of fiat, the options monetary authorities had for monetary expansion were quite limited, unless they could get their hands on bullion.

Precious metals in western Europe were available in inelastic supply for most of the medieval period (Braudel and Spooner 1967, p. 384).[11] With the Black Death during the mid-fourteenth century the effective availability of per capita precious metals did increase, and pressure lessened. But not a century had passed until economic growth was strangling available supplies of specie and increasing the price of precious metals used in coins. Historians speak of a deflationary "late medieval bullion famine" (Day 1978; Sussman 1998 for a critical review). While broader forms of money were available, there are both theoretical and empirical reasons to believe they were more complementary than substitutes to currency (Nightingale 1990, Capie 2004, Mayhew 1999, Palma 2016b). For this reason, monetary expansion was constrained.[12] Since the major input in the production of money in a commodity money system is bullion, and bullion was available in inelastic supply during most of the middle ages, money supply was nearly fixed as well. The

[8] In the robustness section, we also show that the increase in income levels had only a marginal effect on trade levels.

[9] See O'Brien and Palma (2016) for the history of the regime change to a paper money system.

[10] We focus here on silver and gold. Copper was mostly used for small transactions.

[11] For this reason there were persistent deflationary tendencies throughout most of the period (Cipolla 1993, p. 171, 214).

[12] In China, in turn, there was a recurrent problem of scarce availability of precious metals relative to the size of the economy. In the words of Pomeranz and Topik (2000, p. 14), "[e]ndless books have been written about the dangers of government printing too much money. But for centuries the opposite problem was just as common: governments often couldn't mint enough coins (...) to meet their subjects' needs." See also von Glahn (1996).

limited availability of coinage metals (alloys) meant that monetary policy was restricted by the equilibrium in the specie market.

From the mid-fifteenth century to about 1520, the exploration of west Africa coast by the Portuguese brought to Europe quantities of gold at lower cost than had been previously entering with the trans-Saharan caravan trade, but it is not clear if net positive quantities entered in this way. During the fifteenth century there was also increasing production of silver in Burgundy, Saxony and Bohemia and associated technical change made silver available at lower cost than had been previously possible (Munro 2003, Cipolla 1993, p. 174). But these quantities were small compared with those to come.

After 1492, Europe experienced monetary injections of unprecedented magnitude as a result of the discovery of America. The first wave was compromised of gold in moderate quantities which the Spanish brought from the Caribbean (Vilar 1969). Next there was plunder the Spanish took from the Central American civilizations, and in turn this was followed by mining of silver at Potosí, and Mexico. The last sources were of considerable magnitude, and were further combined with purifying techniques developed in central Europe in order to produce unusually large monetary injections. Finally, in the eighteenth century large gold reserves were found by the Portuguese in Brazil, and the Spanish compensated decreased volumes of silver production in Potosí with increased production in Mexico. Figure 1 shows the distribution of precious metals mined in time and space. We discuss the amounts in detail under the next subsection.

2.2 American precious metals

From 1500 to 1800, 85% of the world's silver and over 70% of world's gold came from America (Barrett 1990; see also TePaske 2010, p. 111, for similar figures). Japan was also a producer in the 1500s. The 1500-1800 period was one of unprecedented injections. Tables 1 and 2 provide a perspective. Table 1 shows the quantities of precious metals produced in America each century. Table 2 shows arrivals to Europe by comparison with the initial stocks of Europe. For similar figures see the discussion of Jacob's estimates in Braudel and Spooner (1969, p. 444), endorsed by Velde and Webber (2000, p. 1230) who also quote other scholars who arrived at similar figures for 1500.[13]

In order to turn figures for silver and gold into a common unit, in Table 2 we have used the relative price of gold in terms of silver (from Neal 1990). We assume that European markets were sufficiently integrated that this ratio was approximately true elsewhere in Europe.[14] This

[13] Braudel and Spooner (1967, p. 445) also give estimates for stocks of precious metals in Europe during the early modern period. However, these estimates are unusable as they rely on implausible assumptions. In particular they assume that all production of American precious metals came to, and stayed, in Europe. This ignores the fact that some stayed in America, but more importantly much went to Asia through the Pacific, or, having come to Europe, was subsequently exported to Asia or elsewhere. Also, gold needs to be accounted for. While it was mostly silver that mattered for trade with Asia, the availability of gold as a substitute in Europe meant that more silver was available to be shipped.

[14] There is evidence that a considerable degree of integration existed in both Europe and Asia during the early modern period (Jacks 2004, Pomeranz 2001, Shiue and Keller 2007, Shiue 2002, Li 2002). See Ozmucur and Pamuk (2007) for a contrary view and Federico (2001) for a comprehensive review of all the evidence.

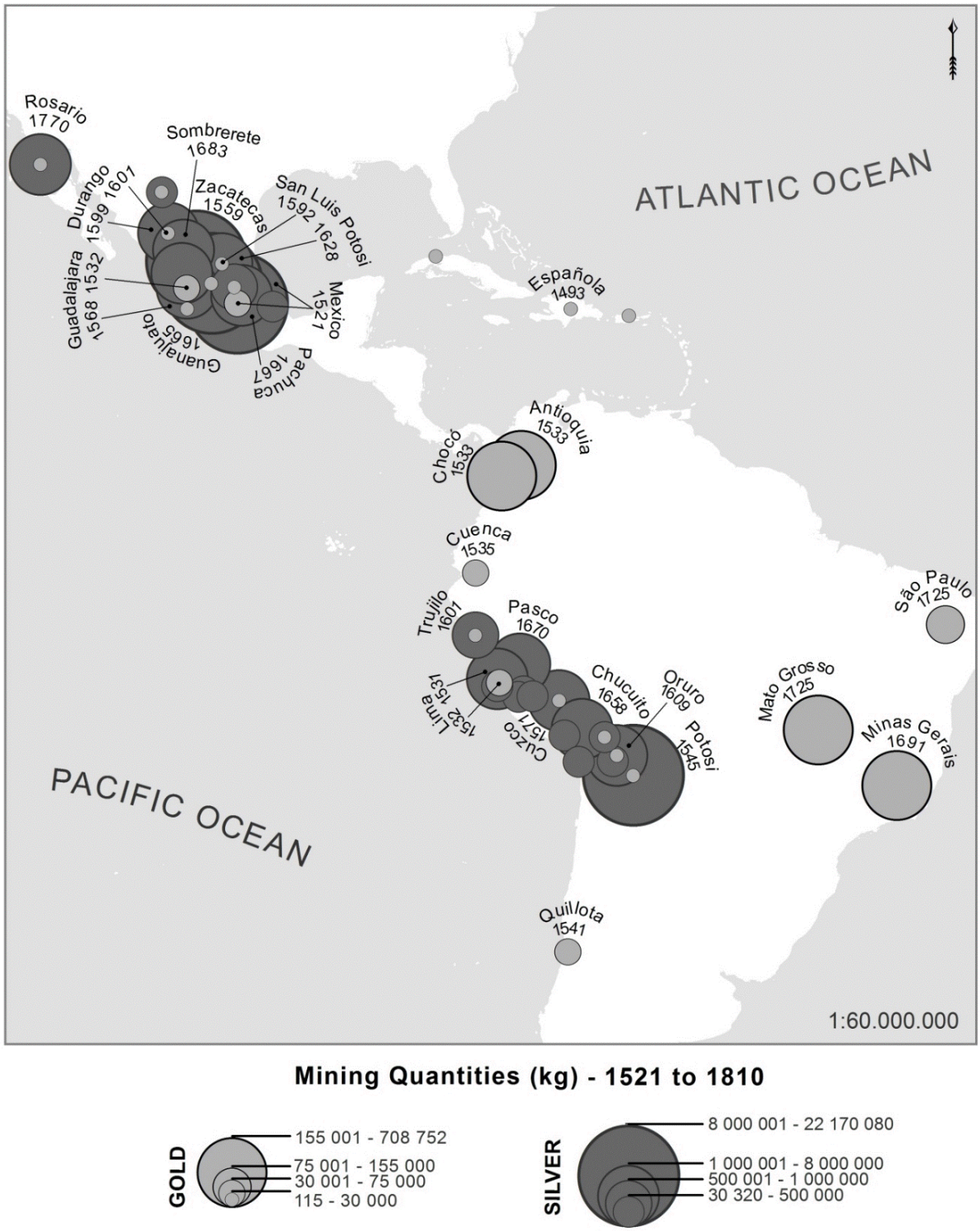


Figure 1: Location of the mines, initial date of records and mining quantities. Source: Palma (2016d), based on data collected by TePaske (2010).

Table 1: Production of Precious Metals in America (silver-equivalent tonnes)

	Lower Bound Estimate	Upper Bound Estimate
16th c.	17,500	21,000
17th c.	33,800	42,500
18th c.	74,000	84,400
Total	125,300	147,900

Source: Barrett (1990, p. 228).

suggests that the initial nominal money supply in Europe was $m^E_{1492} = 6913$ tonnes of silver. Then, assuming no depreciation, and no other sources of production in addition to those related to American precious metals, we obtain a measure of the monetary injection for each half century.[15]

Table 2: Specie Stocks in Europe and Flows

	Fine Silver (tonnes)	Gold (tonnes)	Total (silver equivalent tonnes)
Initial Stock (1492)	3,600	297	6,913
Imports			
1500-1600	7,500	150	9,173
1601-1700	26,168	158	27,891
1701-1800	39,157	1400	60,255
Total Imports	72,825	1,708	97,320

Source: Initial stock from Braudel and Spooner (1969, p. 444). Flows from Morineau (2009). Bimetallic ratios and conversion at the London rates from Neal (1990) and McCusker (1978).

These figures are immediately suggestive of the magnitude of the injections.[16] Notice that for 1500-1800, Barrett (1990) gives a lower bound of 150,000 tonnes of silver *produced* in Latin America. Hence if both figures are correct, less than 50% of the total ever arrived to Europe, as some of it went to Asia and elsewhere through Manila and some stayed in the New World (an amount which would have been initially small, but increased with time).

Tables 1 and 2 show the magnitudes of imports of precious metals. We now discuss the timing of production, and provide a more extensive discussion of the transmission flows. There exists complementary information about the timing of production and shipping flows (Hamilton 1970, Morineau 2009, Attman 1986, Phillips 1990, p. 84, DeVries 2003). These estimates differ in many respects: there is disagreement over the amount of arrivals as well as their timing. While Hamilton presents declining production during the seventeenth century, Barrett's European arrivals data,

[15] A figure including Munro's sixteenth-century central European production figures (Munro 2003) would be higher, as would one including the unobservable flows which were smuggled.

[16] Comparative figures are given by Hamilton (1970) for 1503-1660 outflows from the Spanish empire to Spain of 16,886 tonnes of fine silver, plus 181 tonnes of gold. Nevertheless, because of smuggling, the imports need to be interpreted as lower bounds.

based on Morineau, show no decline during the seventeenth century (Morineau 2009).[17] We will take as a benchmark the estimates presented in Barrett (1990).

Table 3: Production of Silver and Silver Equivalent Precious Metals, 1500-1800 (tonnes of silver)

	American Production (1)	European Arrivals (2)	Exports via the Pacific* (3) = (1)−(2)	Exports from Europe (4)	Production Remaining in Europe (5) = (2)−(4)
1501-1550	8,500	7,250	1,250	NA	4,833
1551-1600	26,500	20,500	6,000	NA	13,667
1601-1650	36,750	26,750	10,000	11,250	15,500
1651-1700	47,250	35,000	12,250	14,250	20,750
1701-1750	60,000	45,750	14,250	20,000	31,500
1751-1800	88,000	59,500	28,500	75,250	31,000
Total	267,000	194,750	72,250	72,250	117,250

* Precious metals exported to Asia via the Pacific plus remaining production in America. Source: Our calculations, based on Barrett (1990 p. 242).

The debate on the Spanish silver numbers mentioned so far is well known to economic historians. Less well known is the remarkable case of Brazilian gold during the eighteenth century. Recent estimates suggest Brazilian gold shipments to Portugal were about 30% higher that the numbers presented by Morineau, having lasted, in decreasing but still significant quantities, into the early nineteenth century. During 1720 to 1807 alone, about 556 tonnes of gold were imported.[18] Notice that by the time the source begins in 1720, transfers had been going on for 30 years and there must have been of course some additional smuggling which does not show up in the data. All three reasons suggest Brazilian gold may have doubled the stock of gold in Europe (see Table 2). Portugal exported most of this gold to England and other European countries, and the increased Europe-wide availability of gold in turn permitted additional silver exports to Asia. In a final exercise, we consider how large the monetary injections were by comparison with the size of the receiving economy.

In Table 4, we show the relative importance of the total monetary imports relative to European wages.[19] The evidence suggests specie injections were of considerable real magnitude. It was the size of several days of work for the regions of Europe with the smaller nominal wages, and up to the value of a day of work in the most labor-expensive areas. The discovery of specie was associated with increases in the availability of money because specie was the critical input in the production of money. As a consequence, Europe experienced major monetary injections.

[17] Morineau argues there was no decline during the seventeenth century as the officially reported decline is cancelled by increased contraband.

[18] Costa, Sousa and Rocha (2013) complement previous sources with information from on-board tax records, *livros do manifesto*. The main reason previous estimates are underestimates is that much currency was minted directly in Brazil (especially during the later periods), so evidence from the Lisbon mint is incomplete.

[19] The construction of this table is detailed in the Appendix.

Table 4: Importance of Monetary Imports Relative to European Wages (grams of silver)

	American Production (per capita)	Imports (per capita)	Wage, unskilled (per day)	Wage, skilled (per day)
1501-1549	3.2	2.8	2.1–4.2	2.8–6.8
1550-1559	8.4	6.5	1.9–6.6	3.3–12.5
1600-1649	9.9	7.2	3.2–8.8	5.2–20.1
1650-1699	12.2	9.0	2.7–9.7	3.9–15.1
1700-1749	14.7	11.2	1.9–10.5	3.0–11.7
1750-1799	16.4	11.1	2.9–11.5	3.2–17.8

Source: Allen (2001, p. 416), Maddison (2006, pp. 636, 639).

2.3 Quantifying early modern monetary injections

We now consider the manner in which such an endowment windfall affected monetary variables.[20] Europe and much of Asia were under a commodity money system, and precious metals were the key input for the production of money.[21] International settlements were made in bullion or full-bodied coin valued by weight. Within Europe, coin usually circulated by tale. As mentioned before, although bills of exchange were used within Europe, especially for international payments, and at the local level copper-based coinage was used for small transactions, silver and gold-based coin was by far the most important component of the money supply. There exists some useful but disperse data about money supply for a few European countries during the early modern period (see for instance Mayhew 1995, Palma 2016d, Sousa 2006) but no data is available about aggregate money supply in Europe.

The literature often mentions the association between these injections and early modern Euro-Asian trade. However, without estimates of relative magnitudes, we cannot have a precise idea of their quantitative importance. We now present a calculation of the early modern initial monetary base of Europe and the subsequent monetary shocks. Although coin often circulated by tale—at a value higher than the value of its intrinsic (metal) component—the quantity of bullion available provides a good approximation to the money stock (Findlay and O'Rourke 2003, p. 22).[22] For international trade in particular, the usage of hard money was critical.[23]

Table 5 compares the quantities of precious metals that arrived (M_e+ exports) with those that stayed in Europe (M_e). The table shows the growth of precious metals availability which resulted from the increased availability of precious metals. A monetary injection did not correspond to the actual increase in European money supply during the period, since Europe was not a closed

[20] We note in passing that while most of the "endowment windfall" was obtained by extracting the American metals (other than directly stealing from American native civilizations), such a term is meant to carry no normative content.

[21] In parts of Asia, notably China, there was little difference between bullion and money itself, as we explain below.

[22] Credit existed (even if it was small compared with modern economies) but most importantly, the multiplier was much smaller since there were much greater collateral requirements due to higher transaction costs and much deficient contract enforcement and other commitment mechanisms.

[23] Lack of an enforcement mechanism meant there were no bills of exchange or other debt mechanisms of notice used in transactions involving Asia.

economy. For the purpose of the model in this paper, what is relevant is not the change in the effective stock of precious metals available in Europe, but the actual size of the monetary injection before external trade is considered. Since exports are endogenous in the model, and the model is set up in representative agent terms, the second column is what is needed to determine the magnitudes in the model.

Table 5: Holdings of Precious Metal in Europe (aggregate and per capita)

	M_e plus exports (tonnes)	m_e plus exports (grams per capita)	M_e (tonnes)	m_e (grams per capita)
1492			6,913	121
1500-1549	14,164	247	11,747	205
1550-1599	34,664	529	27,832	425
1600-1649	61,414	832	50,164	608
1650-1699	96,414	1,242	82,164	1,059
1700-1749	142,164	1,745	122,164	1,500
1750-1799	201,664	1,880	181,164	1,689

M_e and m_e plus exports denote precious metals and precious metals per capita in Europe if there were no exports. Note that the variables in table 3 concern flows whereas variables here concern stocks. Population for 1500 used in 1492. Sources: Table 3 and, for population, the next subsection

2.4 Population and output in Europe and Asia

We now discuss the relative size and absolute level of standard of living, for both Europe and Asia, and according to different criteria. We will then use these figures in the calibration of our model. These figures immediately clarify one important matter: the first-order receiving economy for American precious metals, Europe, was by far the smallest, since Asia's population was five times larger.

Table 6: Population and Output in Europe and Asia

	Population (thousands)			Real Output per capita		
Year	Western Europe	Asia	Ratio	Western Europe, y_E	Asia, y_A	$\frac{y_E}{y_A}$
1500	57,268	268,400	0.213	771	572	1.34
1600	73,778	360,000	0.205	890	575	1.55
1700	81,460	374,800	0.217	998	571	1.75
1820	133,040	679,400	0.196	1204	577	2.08

Real output per capita in Geary-Khamis international dollars of 1990. Western Europe includes Spain and Portugal. Asia excludes Japan. Source: Maddison (2006, pp. 636, 642).

Table 6 reproduces Maddison's figures for both per capita income and population. In Maddison's data, all of Western European real output per capita is rising during the early modern period, and Europe comes off always better than China, even in the earlier periods. There is a debate on whether this was true for Western Europe as a whole or just for its leading economies, Holland and Britain. Indeed, some scholars have questioned whether Europe was richer than Asia

until the nineteenth century, and claim that once a better measure for the price level is taken into consideration, early modern per capita real output in Europe may on the whole not have been higher than that of Asia, in particular China's (Allen 2005, Pomeranz 2000). Others have disputed this; for a view more favorable to Western Europe, see, for instance, Broadberry and Gupta (2006). A compromise is possible if in the early modern era some parts of Europe were pulling ahead and most of Asia looked more like those parts of Europe that were lagging (Allen 2001, 2005, Allen et al 2011, van Zanden and van Leuween 2012, Broaberry et al 2015).[24] While substantial improvements to Maddison's GDP data already exist for a number of European countries in this period, as well as for China (Broadberry et al 2015), no comparable data exists for either Europe or Asia a whole.[25] Hence we stay with Maddison's estimates, as no viable alternative exists at present. In any case, our main results are not sensitive to plausible changes in benchmark income levels or growth rates.[26]

2.5 European demand for Asian luxuries

The Voyages of the Discoveries were motivated by the search for Asian luxuries. When Vasco da Gama sailed for India in 1497, he had specific instructions from the Portuguese king to find spices, Christians, and porcellanas (Atwell 1998, p. 380). Contemporary observers noticed continued European interest in Asian luxuries. The Portuguese Jesuit Gaspar da Cruz, one of the first Europeans to provide a detailed description of China (and the most accurate according to Boxer 2004), described Sino-Portuguese trade in 1569 as "five or six carracks coming laden with silk and porcelain" (Boxer 2004, p. 112). Two centuries later, European interest in Asian goods remained high.

Adam Smith commented on the continued importance of the East Indies "in taking off a greater and greater quantity of silver" (Smith 2003, p. 278). He attributed this to the fact that Asia had larger and more developed markets. About the demand for precious metals in Asia, Smith notes that "[I]n the East Indies, particularly in China and Indostan, the value of the precious metals, when the Europeans first began to trade to those countries, was much higher than in Europe; and it still continues to be so" (p. 279).[27]

Europeans were interested in Asian goods, in particular luxury goods that were cheaper to transport over long distances: silk, porcelain and, slightly later, tea from China; spices, pepper,

[24] Nonetheless, the difficulty of measuring comparable real income levels for a period so far back in time means that the notion of an early modern little divergence within Europe is questionable until relatively late in the early modern period (Palma and Reis 2016).

[25] The alternative that exists concerns real wages, but even then, data for China is very much incomplete before the mid-eighteenth century (Allen 2005, Allet et al 2011). Further, as it is known, wages only provide a good approximation for comparisons across time and space if the share of workers in the population, the number of days worked and the share of wage income in total income are approximately invariant over time (Angeles 2008).

[26] Plausible changes in population estimates do not lead to significant differences in the results. This is illustrated by the case of the country with the biggest population, China, for which an alternative does exist (Deng 2004). The basic results do not change if instead Deng's numbers are used for China.

[27] See Subrahmanyam (2012) and Boyajian (2007) in relation to Portuguese trade with Asia, and Prakash (2001) in relation to English and Dutch trade with India.

drugs, aromatic substances and cotton cloth (such as printed calicoes and muslins) from India and Southeast Asia. This interest was not exclusive to Europe and its colonies: Asian luxuries such as Chinese silk and porcelain, Southeast Asian spices and Indian textiles were perceived as the pinnacle of sophistication everywhere and sought after by the elites of the Middle East and East Africa, not to mention intra-Asian demand.[28] Some of these goods could only reach the west in meaningful quantities after the opening of the sea routes. The fragile nature of Chinese porcelain, in particular, implied that it was very difficult to transport overland to Europe. Yet, the opening of the sea routes did not by itself lead to a trade boom, because the European interest in Asian luxuries did not find a reciprocal demand.

2.6 Asian demand for precious metals

Historians who point out the causal importance of metals in promoting Euro-Asian trade often state that Asian consumers showed no interest in European consumer goods. Maddison (2007), for instance, writes that "Spanish plunder was mainly in the form of precious metals. These were very important in financing European trade with Asians, *who were not very interested in buying European products*" (p. 312).[29] To our knowledge, there are only two examples in the literature of an alternative, primarily economic, explanation. The first is provided by Chaudhuri (1963), who writes that:

> It has generally been assumed that European goods could not be sold in Asia because of an extremely low elasticity of demand due to the rigidity of consumer tastes (...) [but] the root cause for the drain of precious metal from Europe to Asia at this time is to be found in a marked and wide disparity in the value of gold and silver in terms of commodities. (...) The real price of silver which was the current monetary standard in Asia was much higher there than in Europe, and this in effect meant that the difference in the relative level of prices would have hindered, even if the conditions had been favourable for European goods, any attempt to increase their export from (...) [any] European country to Asia.

However, this explanation takes prices as given rather than being the result of equilibrium outcomes. In contrast, we obtain equilibrium prices after the discoveries of precious metals and trading routes, and calculate the corresponding flows of goods and precious metals. The second primarily economic explanation is provided by DeVries (2003), who argues that growing Asian demand for precious metals was related to growing population and monetization in that area, and that European exports of precious metals were never sufficient to fully compensate for those sources of demand. Our results provide quantitative support for this aspect of DeVries's argument.

[28] Large quantities of Ming porcelain have been found in Southeast Asia, Sri Lanka, India, Syria, Iraq, Egypt, and East Africa; in the Middle East great collections exist in the Topkapi Sarayi Miizesi in Istanbul and that of the Ardebil Shrine in the Archaeological Museum in Tehran (Atwell 1998, p. 379). A manifestation of the interest in porcelains as a status goods is reflected in their frequent depiction in Middle Eastern (as well as European) art.

[29] The context of the sentence suggests Maddison had a cultural explanation in mind. See also Pearson (2001, p. 23, Cranmer-Byng and Wills 2011, p. 216).

It is a fact that Asian consumers did not demand European goods, only precious metals. The Chinese case is the best documented, and the most important. Chinese traders were disdainful of foreign manufactured goods and demanded payment in silver (Atwell 1998, p. 380-1). Although China was not interested in most goods produced in Europe, it was very interested in precious commodities, as they were a source of credible monetization of its large economy.[30] Accordingly, "Undoubtedly China was the main and ultimate destination—directly or through intermediaries—of Spanish American silver since the sixteenth century" (Irigoin 2009, p. 207, fn. 1). First hand observers such as Gaspar da Cruz share this view (Boxer 2004, p. 112). Pomeranz and Topik (2005, p. 16) summarize the situation as follows: "Long distance trade recovered and then reached new heights in the 1500's, but then a new medium of exchange was available, silver (...) For the next 300 years, close to half of the world's silver production found its way to China's money supply (...) while becoming the way for long distance trade."

India followed the same pattern. At least until in the mid-eighteenth century, trade was based on export of American bullion by Europe in exchange for Indian textiles (Prakash 2003, 2004, Steensgaard 1995, Darwin 2008, p. 149). For Southeast Asia, analogously, there was little demand for European goods other than precious metals (Pearson 2001), and we have evidence that over this period silver became the base metal for transactions.[31]

Euro-Asian trade was residual during the middle ages. Before American precious metals became available and the maritime trade routes to Asia were open (both through the Cape and through the Pacific), the small trade flows simply reflected equilibrium responses to relative endowments and price levels. It was only after 1500 that internal developments in Asia, advances in European maritime technology and the discovery of American treasure interacted to ensure that there was scope for trade; see DeVries (2003) for quantitative data on departing and returned ships, tonnage, and personnel.[32]

Since Asia did not show much interest in European goods, Asian imports had to be paid for in bullion. Europe and its colonies paid 90% of their imports from China during the early modern era using silver (Pomeranz 2001, p. 159).[33] Most of the silver which Europeans brought to Asia, in turn, went to China. A conservative estimate is that 75% of the combined 400 million pesos of Spanish American silver bound to the Philippines during 1565-1820 ended up in China to pay for

[30] Glahn (1996, p. 201), Pomeranz (2000, p. 4 and p. 159), Flynn and Giraldez (1995, p. 429-30), Boxer (1970). First hand observers writing until the last quarter of the sixteenth century typically refer to silver being used as such for transaction purposes. For instance, Martin da Rada, who visited Fujian in 1575, writes that "everything is bought by weight and with little bits of silver" (Boxer 2004, p. 407). Later writers increasingly notice minted Spanish pesos in circulation (Atwell 1998, p. 380-1). We also note in passing that China did not have any significant internal source of precious metals, being that its silver mines had been exhausted by 1430 (Glahn 1996, p. 114)

[31] For instance in Burma, during the period 1750-1830 about 97% of land sales were made exclusively in silver (Tarling 2000, p. 235).

[32] DeVries also provides numbers on the growth of Euro-Asian trade during the early modern period, measured by volume and value.

[33] The lower estimate we know of gives 80 to 90% paid for in silver up to 1760, and about 50% thereafter (Cranmer-Byng and Wills 2001, p. 220). As it is well known, England's opium trade with China started from the middle of the 18th century onwards as a strategic action with the (ultimately successful) intent of lowering the remarkable trade deficit, paid for in silver.

imports.[34] The single most important Chinese export was silk. At the peak of this trade, China exported silk goods of value up to four million pesos per year (Ma 1998).

According to Adam Smith, two aspects justified a low price of Asian manufactured goods relative to European goods. First, Asian nominal wages were low. This claim has modern empirical support: Allen (2005) attributes Asia's proximate cause of competitive advantage in textiles and luxury manufactures to low nominal wages. This might be partially compensated by low food prices but it would nevertheless meant Europeans had cheaper access to imported Asian goods than conversely. Adam Smith also stated that China was able to support "great manufactures" as a result of the division of labor made possible by a large internal market (Smith 2003, p. 280 and 866). For Smith, the fact that China had a larger market than Europe explained the reason why the value of precious metals was higher in China, but differences persisted because of transport costs, which prevented unconditional arbitrage (Smith 2003, p. 257).

The mere relative size of Asia's economy, shown in Table 6, would suggest that absent significant barriers to trade much American treasure would end up in Asia. Indeed this was the case. Pomeranz (2001, p. 190) argues that between one third and one half of all New World silver ended up in China alone.[35] When New World silver began to be available to Europeans, the gold-silver price ratio in was 1:6, while in Europe it was between 1:11 and 1:12 (Glahn 1996, p. 214). This suggests enormous arbitrage gains, even under the prevailing transport technology and institutional settings. Although we do not have much systematic evidence, what we do know about imports suggests much American treasure in fact ended up in Asia (Brook 2006, p. 161, Glahn 1996, Irigoin 2009, 2013).

Another support for the importance of precious metals in Asia is the evidence about the scarcity in this region of means of payments.[36] Following failed experiments with paper money (the government inability to commit to limited supply led to hyperinflation and the public's confidence was over by 1425), the Ming government was unable to prevent widespread use of silver as store of value and means of transaction. Following the state's official acceptance of silver by the mid-1430s, silver displaced all other currencies and by mid-century China was a silver economy (Glhan 1996, p. 79; see also Atwell 1998, p. 381-188). Finally the government itself adopted silver

[34] One silver peso of 8 reales or 272 maravedís corresponds to 25.931 grams of silver (Munro 2003). This rate between a nominal amount and a physical weight operated in a time-invariant way during the entire Early Modern period.

[35] The role of China as the ultimate destination for American silver during the early modern period has been criticized by Deng (2008). However, Deng is interested on the effect and overall importance of silver for the Chinese economy, while our focus is on understanding the causal importance of silver in explaining the volume of Euro-Asian trade, as well as the nature of that trade, during the same period. Hence for our research question to make sense what matters is that Europeans imported luxury goods in exchange for large amounts of silver. To the extent of our knowledge no historian questions these two premises. Deng elsewhere recognizes early modern silver imports into China were sufficient to "cause the money supply curve to shift to the right by a great margin" Deng (2007, p. 331). Indeed, wishing to estimate Chinese exports, Deng takes as a maintained assumption that China's exports were meant exclusively for buying silver Deng (2008, p. 324).

[36] von Glahn (1996) provides an excellent description for the most important economy, China. It is also the case that "In India (...) the demand for monetary metals grew rapidly as export-oriented textile trades extended market relations into ever-widening hinterlands that previously had been reliant on payments in kind" and that "The monetization of an economy the size of South Asia (where the population appears to have doubled between 1500 and 1800) supported a dynamic demand for silver and gold" (DeVries 2003, p. 96)

as means of tax payment. An unified tax system known as Single-Whip was established in the 1570s; it consolidated all labor taxes into one, specified to be paid in silver. China had one fourth of the world's population at this time, with urban centers of one million or more, and demand further extended to the neighborhood Asian countries which were covered by China's silver-based extensive tributary system (Flynn and Giraldez 1995b). Accordingly, during the sixteenth century, "Spanish [silver] rials served as the international currency of much of maritime Asia, as well as Europe" (Glhan 1996, p. 282, n. 44; see also Reid 1995, p. 26). These facts exerted a strong pull of silver towards Asia (Table 7).[37]

Table 7: Exports of Silver and Gold from Western Europe, 1601-1780 (tonnes of silver equivalent)

	To the Baltic	To West Asia	VOC to Asia	EIC to Asia	Total to Asia
1601-1650	2,475	2,500	425	250	4,006
1651-1700	2,800	2,500	775	1,050	4,847
1701-1750	2,800	2,500	2,200	2,450	7,900
1751-1780	1,980	1,500	1,445	1,450	5,270
Total	10,055	9,000	4,845	5,200	22,027

VOC: Vereenigde Oost-Indische Compagnie (Dutch East India Company). EIC: English India Company. Source: Maddison (2007, p. 113), Barrett (1990). During the same period 9,000 tonnes went to the Eastern Mediterranean, and it is possible some of this ended up in Asia as well (Maddison 2006, p. 67). Total to Asia differs from Barrett and Maddison by the inclusion of totals sent through the Philippines (Barrett 1990).

These numbers compare favorably with the total silver and gold production in Spanish and Portuguese America: between 27,640 and 34,435 silver-equivalent tonnes were produced during the seventeenth century, and between 39,157 and 58,530 during the eighteenth century (Barrett 1990, p. 228). Nonetheless, some historians claim most of the flow of precious metals from Europe to the East actually went through the Levant (Pearson 2001), which is not included in Table 7. Furthermore, the trading activities of the Spanish, as well as the Portuguese Estado da Índia are not included in the table. Finally, smuggling was also common.[38] All these considerations suggest the amounts in Table 7 are lower bounds to the totals which actually went to Asia, which would have been at least half of the totals produced in America, as discussed above.

In Japan, silver mines were also discovered during the sixteenth century. The Japanese windfall also provided arbitrage opportunities for Europeans operating in Asian waters. But the relative importance of Japanese silver during the early modern era was small. Even at its peak in the sixteenth century, "[s]ilver was available to Manila merchants more readily and in greater quantity from America than to the Portuguese of Macao from either Japan or Goa. As early as 1580 far more silver was reaching China via the Pacific from Mexico and Peru than from any other single source" (Boyajian 2007, p. 64).

[37] The injections to China were such that by the early nineteenth century the breakdown of the South American monetary system had serious consequences in China (Irigoin 2009, 2013).

[38] Chinese trade with Europeans, internally justified as "tribute from barbarians," was under a large number of restrictions and regulations by the Chinese state, and it is plausible much of it operated through smuggling.

3 A quantitative model of early modern Euro-Asian trade

We introduce a dynamic general equilibrium model of international trade with two countries, two goods and money. The demand for money is obtained with a money-in-utility specification.[39] In the model there are two agents, denoted Europe and Asia, with identical preferences but different endowments. Each agent produces a domestic good. All of the silver windfall is given to the European agent. There are also transaction costs, which apply to international transactions only.[40] Because of high transport and agency costs during this period, luxuries were the only goods that could be profitably transported over large distances.[41] In exchange, Europe paid with precious metals, which were even cheaper to transport.[42] Each trading expedition had an associated return voyage. Given the impossibility of debt, trade deficits were paid for in money. The parameters are calibrated in accordance to the historical evidence.

The windfall in the model is given in silver-equivalent units.[43] The model assumes equivalence between bullion and money, which is a simplification, though not far from historical reality for China and many other parts of Asia. For instance, Brook (2006 p. 160) writes that "By the sixteenth century, prices in China for anything but the smallest transactions were calibrated by weight of silver, not by unit of currency (...) [Spanish] reals were circulating as something like an international currency in Southeast Asia."[44] In turn, Europe's prevailing commodity money system meant that precious metals were the fundamental input for the production of money, and people could freely convert precious metals into coin at the mint.[45]

The objective of our model is to compare the historically observed scenario with the no-windfall counterfactual. We compare the two equilibria under different sequences of precious metals given

[39] This can be seen as the reduced form of a more explicitly micro-founded shopping-time model.

[40] It is an iceberg-cost model which works as if part of the equilibrium amount of exports disappear in transit before they arrive at their destination. Transaction costs relate to the efficiency with which the shipping and trading activities were conducted and hence are to be interpreted as including both transportation and agency costs. They include "the construction and operation of ships, the [construction,] maintenance and defense of trading factories in Asia, administrative expenses, bribes and payoffs, and interest on borrowed capital" (DeVries 2003, p. 83).

[41] Transportation costs also implicitly include the increased risk of international trade.

[42] As Adam Smith put it, "the transportation of those metals from one place to another, on account of their small bulk and great value, is less expensive than that of almost any other foreign goods of equal value. Their freight is much less, and their insurance is not greater; and no goods, besides, are less liable to suffer by the carriage" (Smith 2003, p. 471).

[43] Spanish silver dollars were the de facto numeraire and of wide acceptance in not just the Spanish Empire but much of the world. Many examples survive with Chinese counterstamps , which permitted the circulation of these dollars in China. They were also commonly used in Southeast Asia and the United States well into the nineteenth century; in the US they were legal tender until 1857.

[44] The fact that, particularly in China, there was no essential distinction between silver and currency is illustrated by the fact that the silver money of account (*liang*) was identical to its actual weight in silver (Glhan 1996, p. 42). See also Irigoin (2009). Deng's claim that the "use of silver [in China] was biased towards services and consumption, not production" (Deng 2008, p. 352) is in line with our transactions-driven demand for money interpretation. A helpful summary is also given by Brook (2006, p. 172): "Silver flowed easily into the Chinese economy because it was needed to supplement the small bronze coins that were used for small transactions. It was the standard form of money; it was also the form in which the Ming regime collected taxes."

[45] Strictly speaking, bullion was the fundamental input for the production of specie. At the same time, as we argued in section 2.1., specie and broader forms of money were at this time complements, not substitutes.

to the European agent. In the counterfactual situation, the European agent gets no windfall. In the second situation, it gets the historically observed windfall.[46] Furthermore, international trade in goods incurs an exogenous iceberg cost of b.[47] The European agent solves

$$\max_{c_{ee},c_{ea},m_{et}} \sum_{t=0}^{\infty} \beta^t u\left(c_{ee}, c_{ea}, m_{et}\right) \tag{1}$$

$$\text{s.t.} \quad p_{1t}c_{eet} + p_{2t}c_{eat}\left(1+b\right) + m_{et} \leq p_{1t}A_e + m_{e,t-1} + d_t. \tag{2}$$

In problem (1)-(2), c_{eet} denotes consumption by the European agent of the European good in period t, and c_{eat} is consumption by the European agent of the Asian good in period t. m_{et} is the money stock held by the European agent in period t. The function u has the usual well-behaved properties; we consider a specific functional form below. In the budget constraint, $m_{e,t-1} \geq 0$ is the money left over, p_{1t} is the price of the European good, and p_{2t} is the price of the Asian good. In period t, the European agent receives a monetary windfall of d_{et}. There is an exogenous iceberg transaction cost b incurred when purchasing foreign goods. The Asian agent solves a similar problem, but never gets a windfall ($d_{at} \equiv 0$ for all t).

The first-order conditions of problem (1)-(2) imply the equilibrium conditions

$$\frac{c_{eet}}{c_{eat}} = \frac{\omega}{1-\omega}\left(\frac{p_{2t}\left(1+b\right)}{p_{1t}}\right)^{\gamma}, \tag{3}$$

$$\left(1-a\right)m_{et}^{\eta-1} = ac_{et}^{\eta-1}\frac{\partial c_{et}}{\partial c_{eet}}\frac{1}{p_{1t}} - \beta\left[\frac{ac_{et+1}^{\eta}+\left(1-a\right)m_{et+1}^{\eta}}{ac_{et}^{\eta}+\left(1-a\right)m_{et}^{\eta}}\right]^{\frac{1-\sigma-\eta}{\eta}} ac_{et+1}^{\eta-1}\frac{\partial c_{et+1}}{\partial c_{eet+1}}\frac{1}{p_{1t+1}}. \tag{4}$$

Equation (3) equates the marginal rates of substitution of intratemporal consumption and equation (4) is an intertemporal Euler equation for money. Given the assumed preferences all constraints bind for each agent. The market clearing conditions are given by

$$L_e c_{eet} + L_a c_{aet}\left(1+b\right) = L_e A_e, \tag{5}$$

$$L_e c_{eat}\left(1+b\right) + L_a c_{aat} = L_a A_a, \tag{6}$$

$$L_e m_{e,t} + L_a m_{a,t} = L_e m_{e,t-1} + L_e d_t + L_a m_{a,t-1}, \tag{7}$$

where L_e is the population of Europe and L_a of Asia. Transaction costs b take part in the goods market clearing conditions (which are also aggregate resource constraints) because of their iceberg effect—is as if some of the goods traded internationally were lost in transit. The last equation is a money market clearing equation. One of these three equations is redundant by Walras's law.

The full system has eight equations (4 Euler equations, 2 budget constraints, and 2 market clearing conditions) and eight endogenous variables. In the system, at time t, the endogenous variables are given by the vector $[c_{eet}, c_{eet}, c_{eat}, c_{aat}, m_{et}, m_{at}, p_{1t}, p_{2t}]'$ and the state variables are given by $[m_{et-1}, m_{at-1}, d_t]'$. The discoveries sequence $\{d_t\}$ corresponds to an exogenous endowment stream which adds to Europe's money supply. A sequence of markets equilibrium is a collection of allocations and prices characterized by the first-order conditions to each household's optimization problem, the budget constraint, and two market clearing conditions.

[46] We abstract so far from considering labor or capital markets. In the robustness section, we present an extension with capital, where capital is immobile across continents but goods and money are tradable.

[47] Transaction cost here stands for both transportation and agency costs.

3.1 Functional forms

We specialize in the following CES functional form, here shown for the European agent,

$$\begin{aligned} u\left(c_{et}, m_{et}\right) &= \frac{\left[a c_{et}^{\eta} + (1-a)\, m_{et}^{\eta}\right]^{\frac{1-\sigma}{\eta}} - 1}{1-\sigma}, \\ \text{where } c_{et} &\equiv \left[\omega^{\frac{1}{\gamma}} c_{eet}^{\frac{\gamma-1}{\gamma}} + (1-\omega)^{\frac{1}{\gamma}} c_{eat}^{\frac{\gamma-1}{\gamma}}\right]^{\frac{\gamma}{\gamma-1}}. \end{aligned} \tag{8}$$

The variable c_{et} is a composite consumption good for Europe. All parameters are equal for both agents, in line with ruling out a cultural explanation. Specifically, we do not impose that the Asian agent has any particular propensity to hoard precious metals. Under this functional form, any given parameterization of the system has a unique solution with positive prices and allocations.

3.2 Calibration and estimation

We calibrate the model at annual frequency. We take some parameters from the literature while others are estimated using a combination of the structure of the model and historical data. Table 8 shows the values for the parameters that we calibrate.

Table 8: Baseline Parameters

	Parameter	Value
Intertemporal discount factor	β	0.96
Inverse of the elasticity of intertemporal substitution	σ	2
CES parameter of goods and money	η	-2
CES parameter of domestic and imported goods	γ	1.2
Weight on consumption	a	0.81
Population in Europe (millions)	L_e	85
Population in Asia (millions)	L_a	409
Per capita income in Europe	A_e	965.75
Per capita income in Asia	A_a	573.75
Home bias	ω	0.90
Iceberg cost before the new trade routes to Asia	b^i	16.10
Iceberg cost after the new trade routes to Asia	b^f	7.61

Parameters used in the simulations.

We use $\beta = 0.96$ for the intertemporal discount factor and $\sigma = 2$ for the inverse of the elasticity of intertemporal substitution. These are standard values in macro models. The values of a, η, and γ are similar to those used in the trade literature (see, for instance, Duarte and Wolman 2008). We calibrate the populations of Europe and Asia according to empirical evidence on population

shares, based on Maddison's estimates (Maddison 2006, p. 636-638).[48] For real income levels, we use the 1500-1800 average of per capita income from Table 6, $A_e = 965.75$ and $A_a = 573.75$ Geary-Khamis international dollars of 1990 per person. The initial European quantity of silver, $m_{e,1492} = \frac{6913}{57.268} = 120.71$ is the Braudel and Spooner estimate discussed in section 2. We also need $m_{a,1492}$, which we obtain through a quantity theory argument: given the initial nominal per capita income for Europe, we back up initial velocity as $v_e = \frac{A_e L_e p_{1,1492}}{m_{e,1492}}$. We then assume the same velocity applied to Asia, which permits backing up $m_{a,1492}$.[49]

Given these numbers, there are two free parameters left to calibrate, the iceberg cost parameter b, and the home bias parameter ω. We estimate two iceberg cost parameters, for before, b^i, and after, b^f, the Voyages of Discovery. The discovery of a sea route from Europe to Asia cut significantly the cost of trade between these areas. An overland roundtrip to Asia previously took three years (Spufford 2006, p. 344). It could now be done in months, carrying much more cargo under safer and cheaper conditions. The values of b^i, b^f and ω are assumed to be the same for Europe and the Asia. In fact, transportation costs were higher for the Asian agent, which had access to less advanced nautical and military technology.[50] Yet, by putting the Asian agent on equal foot on this manner, we bias the results against our main point as we rule out different pattern of costs as an explanation for the observed imbalance of trade.

Transaction costs here stand for transportation plus administrative and agency costs for intercontinental trade.[51] The goods for which we observed trade in equilibrium were high value-to-weight luxury products. These goods must have been the goods for which transaction costs for intercontinental trade were the lowest. However, given the aggregate nature of the model, we choose b such that it applies to the kind of goods that were in fact traded in equilibrium.[52]

Around the middle of the eighteenth century, the Cape-route trade provided an average Western and Central Europe consumer with Asian goods that cost the equivalent of three days wages of a manual worker in Holland or England: between 0.8 to 1.4% of average annual wage income (DeVries 2003, p. 91).[53] For workers elsewhere, the cost in days of work would be higher, and a working family might spend an average of five days wages per year to acquire such goods. Also,

[48] We take population and output levels as given, hence we assume they are invariant to the shock. Also, in order to focus on Euro-Asian trade patterns we exclude Japan, which exported some silver to other parts of Asia during the sixteenth century.

[49] Our assumption is that since no major precious metals shocks had been occurring for a long time, the world markets should be in a long-term no-arbitrage equilibrium, conditional on the international transaction costs of the time.

[50] The historical fall in b corresponds not only to the finding of a new route per se, but also the associated technological and organizational change.

[51] Is it legitimate to hold transaction costs constant throughout the early modern period? There is evidence that at least for transport costs proper this is a reasonable assumption (Menard 1991, p. 250). After considering a variety of evidence, Menard concludes that in contrast with other routes, "[T]rade between Europe and Asia provides no support for the notion of an early modern transport revolution" (Menard 1991, p. 252).

[52] A richer model would disaggregate consumption into a continuum of tradable goods with varying degrees of transaction costs which would depend on the weight, rather than the value of individual goods. It is possible to show that a reduced form version of such a model is isomorphic to ours, hence also leading to observationally equivalent outcomes.

[53] The 1720-1750 correspond to a peak of importance for the Cape route relative to alternative routes (DeVries 2003, p. 82).

for earlier periods this may have been smaller. At the same time, DeVries' estimates are for the Cape-route only, while our definition of Europe includes its empire, hence the important Pacific trade, via Manila, to the Americas as well (Flynn and Giraldez 1995). Further, to this we should add the Levant and the Baltic routes.[54]

Although to the best of our knowledge no systematic data for the average transportation costs of silk, tea or porcelain exists, we can estimate these indirectly. We find ω and b^f such that, under the factual scenario (i.e., precious metals discovered in America and a sea-route found to Asia), Europeans consume on average 1.2% of their income in Asian goods. This leads to a range of possible parameters. We set a home bias parameter of $\omega = 0.95$, which in turn leads to a final iceberg cost of $b^f = 4.034$. In the robustness section of the paper, we also consider a range of alternatives for both ω and the share of income spent by the European agent on Asian goods.

Finally, we must find b^i, the transaction cost before the discoveries. Cost estimates for the overland route before (or after) 1498, which might be informative about b^i, and how it compares with b^f, are to the best of our knowledge not available. But given ω, we can back-up b^i using information on consumption patterns for late-medieval Euro-Asian trade. Prior to the Discoveries, Euro-Asian trade existed (mainly but not exclusively through Venice), but it was small. In the late fifteenth century, Euro-Asian trade was $660,000$ duncats per year (Spufford 2006, p. 346), and a round-trip to China would take up to three years. Euro-Asian goods worth at least 23.532 tonnes of silver were being imported per year.[55] Spufford writes that at this time the quantity of goods imported "had been much reduced from the highest level at the beginning of the fourteenth century" (p. 346). Hence, we multiply the value by a factor of 5, arriving at 117.66 tonnes of silver.[56]

To make this figure comparable to the analogous one for the early modern period, we divide it by the population in 1500 of the main countries that were served by these trade channels. Using modern borders, these were Italy, England, France, Belgium, Holland, and Germany. While these may not include the full range of Western European countries that were served, at the same time we are forced to use the population level of 1500, which was considerably higher than that of the post-Black Death years. This leads to a population level of $43,792$ thousand (Maddison 2006, p. 636). Per person, this corresponds to about 2.7 grams of silver. As a percentage of nominal income, using a mid-point for the day wage of the sixteenth century (3.15 grams of silver, see Table 3), we arrive at 0.86 days of work, which we round up to 1 day of work. Then assuming people worked 250 days, we conclude that 0.4% is a reasonable number. Unsurprisingly, late medieval Euro-Asian trade was small in per capita terms. Using this figure, we hence find b^i such that this is the equilibrium level of consumption for Europe.

[54] While Attman had placed considerable emphasis on the Baltic and Levant routes, DeVries (2003, pp. 80-81) argues that they were relatively unimportant.

[55] This follows from the fact that at this time 1 duncat = 1.375 pesos (Morineau 2008, p. 73) and one peso of 8 reales = 25.931 grams of silver (Munro 2003).

[56] In the robustness section, we consider a range of alternative values for this parameter.

3.3 Simulation

Data for the annual value of production of precious metals in America is taken from Palma (2016c). The timeline covered is 1531 to 1810 and the unit is grams of silver.[57] The baseline counterfactual corresponds to a situation where precious metals in America and a sea route to Asia did not exist. We also consider a situation where no precious metals were found in America but new sea routes to the East were found, in order to decompose which part of the observed increase in trade can be attributed to each of these factors. Hence, we now consider the following three simulation alternatives:

1. Simulation of the historical scenario: New sea routes to Asia and discoveries of precious metals. In the model, b is set to b^f, and the values of d_t received by the European agent are set to match the historical data.
2. Baseline counterfactual: No routes to Asia found and no discoveries of precious metals (b is set to the baseline counterfactual, $b = b^i$, and $d_t = 0$ for all periods).
3. Alternative counterfactual: New routes to Asia found and no discoveries of precious metals ($b = b^f$ and $d_t = 0$ for all periods).

The results are in Figures 2 and 3, discussed in the next subsection.

3.4 Discussion

What happens after new silver becomes available to Europe? The comparison with the historical outcomes can be given as follows. First, net exports of precious metals by Europe are given by $XM^m_{et} \equiv (m_{e,t-1} + d_t) - m_{e,t}$. Therefore, if $m_{e,t} < (m_{e,t-1} + d_t)$ then Europe exports precious metals. In turn, net exports of precious metals by Asia are given by $XM^m_{at} \equiv m_{a,t-1} - m_{a,t}$. If $m_{a,t} > m_{a,t-1}$ then Asia imports precious metals. Analogously, for the goods,

$$XM^1_{et} \equiv L_e A_e - L_e c_{eet}, \tag{9}$$
$$XM^2_{et} \equiv -L_e c_{eat}, \tag{10}$$
$$XM^1_{at} \equiv -L_a c_{aet}, \tag{11}$$
$$XM^2_{at} \equiv L_a A_a - L_a c_{aat}. \tag{12}$$

The data and results are shown in Figures 2 and 3.

In the upper-left corner of Figure 2, we show that the amount of precious metals produced in America (referred to as discoveries) increased over time. This corresponds to our 1531 to 1810

[57] Palma's data mainly relies on TePaske (2010) and ends in 1790; here we have followed the same procedure until 1810 (see Palma 2016c, p. 26 for details). The latter date marks the end of TePaske's dataset as well as the beginning of the Spanish American wars of independence.

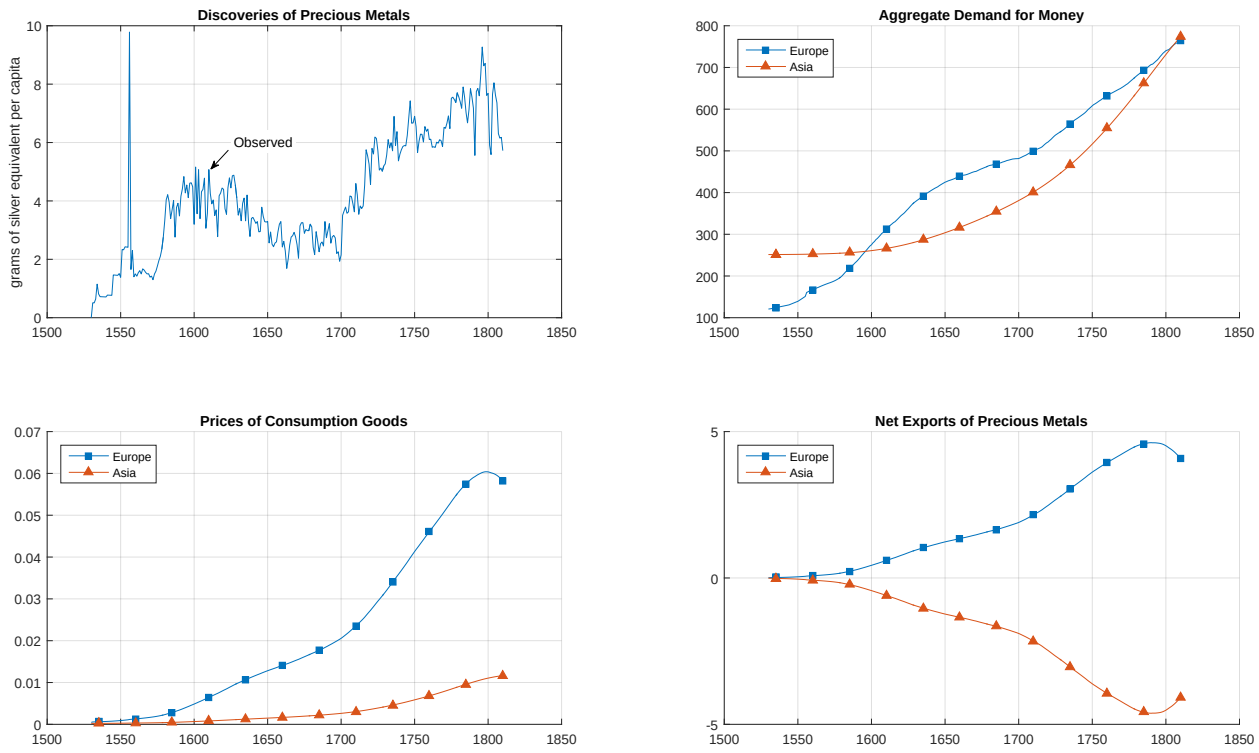


Figure 2: Data on discoveries of precious metals, and simulation results for money demand, prices, and net exports.

data. The remaining panels show the equilibrium response of agents. In the upper right, we see that as the quantity of silver available to Europe increases, demand for money increases for both agents. The lower left panel shows that prices (measured in silver) increase everywhere but do so much more strongly in Europe—that is, the relative price of the European good rises. The lower right panel, in turn, shows that silver is gradually exported to Asia.

European exports as a percentage of discoveries increases until the mid-seventeenth century, henceforth stabilizing at around 60% of discoveries (Figure 3, upper-left corner panel). In Europe, consumption of the Asian goods increases substantially, while consumption of the European good decreases in Asia. The effect on consumption of the national good of either of the agents is much smaller in comparison (Figure 3, remaining panels). These are good predictions in light of what we know since, as discussed above, imports of European goods from Asia—other than precious metals—were negligible, but the imports of Asian goods to Europe were relatively much more important.

How do the results compare with what we know empirically and what else can they tell us? We now show that the magnitudes simulated for the historical scenario are in line with the empirical facts. This should increase our confidence with respective to the model's simulation for the counterfactual scenarios. We now discuss several pieces of evidence in turn.

First, historically, the value of intercontinental trade was only a small fraction of total output. Our model matches this fact well. Intercontinental trade corresponds only to a small fraction of

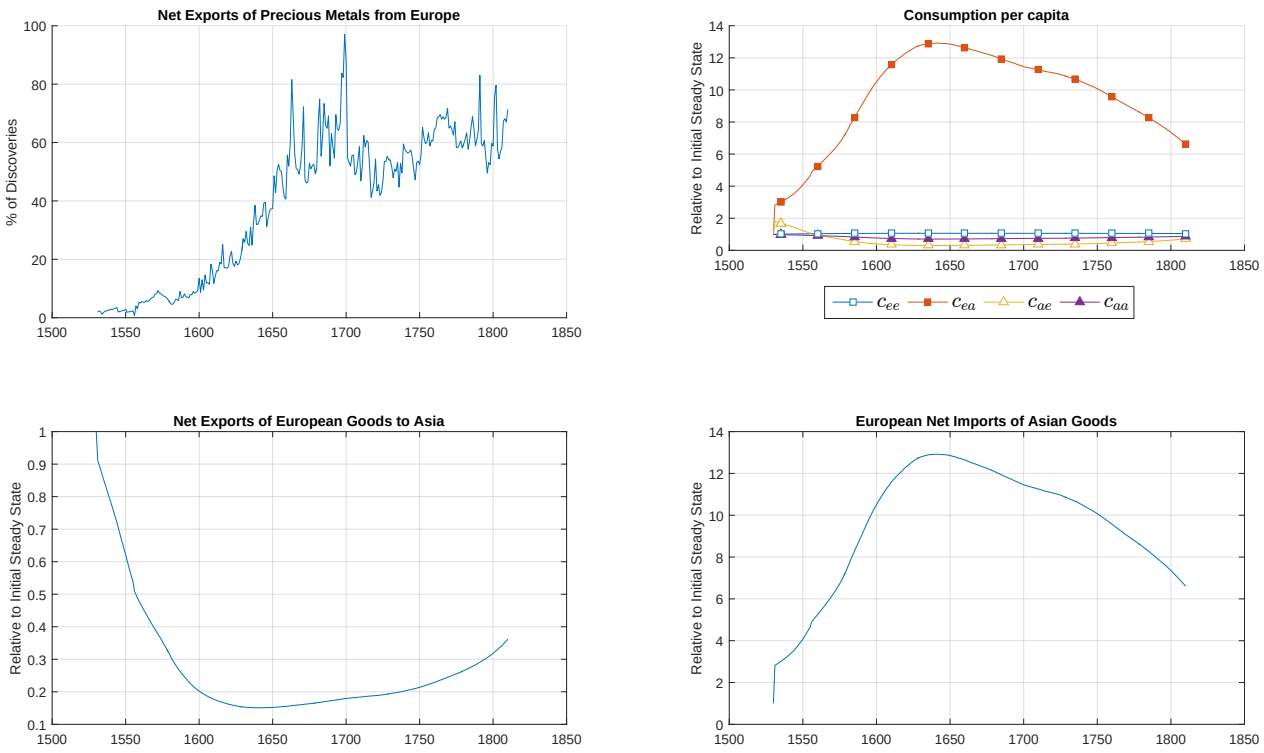


Figure 3: Simulation results for exports of metals, consumption, and goods trade.

total output in our simulation for the historical scenario, corresponding to what was indeed the case. The simulations also suggest that, unsurprisingly, they would have been even smaller under the counterfactual.

Second, over 90% of the value of European exports to Asia during the early modern period consisted of silver. Again, our model matches this well. In the model's simulation for the historical scenario, the main export from Europe to Asia is silver. Relative to the counterfactual, Europe's consumption of both goods increases. At the same time, Asian consumption of Asian goods shows the reverse trend: silver spent on the Asian good is reduced, though by only a little. However, relative to the counterfactual, the imports of the European good to Asia are greatly reduced, to 15% of what they would have been per individual by 1650 (Figure 3, lower-left panel). By contrast, European imports of Asian goods are up to 13 times of what they would have been without European access to American precious metals (Figure 3, upper-right panel). Hence, in the counterfactual with no precious metals, Asia would have consumed more European goods, despite the fact that the total value of Euro-Asian trade would have been smaller. As it was, Asia was deprived of whatever consequences the import of foreign, exotic goods may have resulted for Europe.

The fact that following the shock Asia is able to purchase less of the European good is a surprising implication which comes out of the general equilibrium structure of the model. This results from the fact that there is a wealth or endowment effect, which also has equilibrium consequences for relative prices; in relative terms Asia becomes poorer following the shock which

is given to Europe only. Asia's stock of money is now less compared with the aggregate stock which helps determine prices.[58] This conclusion stands in sharp contrast with some of the traditional interpretations of this episode, which claim that Europe was forced to export bullion to Asia to finance a recurring trade deficit.[59]

Third, Europe experienced a price revolution, but Asia did not (see DeVries 2003, p. 94 and endnote 97, p. 105 for a review of the evidence). Our simulations replicate this well, and they also suggest that the failure of the price level to rise in Asia sufficiently to close arbitrage opportunities through trade is an equilibrium result.[60] Hence, the fact that the value of silver in Asia did not fall sufficiently to eliminate the trade imbalance of early modern Euro-Asian trade is not the result of a particular Asiatic tendency to demonetize precious metals for hoarding purposes, as has long been assumed in the historical literature. Notice that we have been able to reproduce observed history for the factual scenario without assuming different preferences for the Asian agent relative to the European agent—the dominant explanation for these trade patterns in the historical literature.[61] We hence endorse the interpretation of DeVries (2003, p. 96), who also does not agree with the traditional interpretation (which he reviews in endnote 98, p. 105).

Fourth, European consumers had higher real income levels than Asians but not much higher; this was because while nominal wages were considerably higher in Europe, prices were higher too. Historians have long wondered why nominal prices were higher in Europe, and why the difference persisted for so long.[62] Our model offers an answer, even if a stylized one. The difference is partly a result of the real factors: The scarce, European good is owned by a small share of the agents. Because there is a lot less of the European good available, its price should be much higher, but as the counterfactual shows this is largely mitigated by the existence of home-bias and intercontinental transaction costs. Nonetheless, in the counterfactual scenario, the relative price p_1/p_2 is lower than it is under the injection. Furthermore, Europe kept receiving the monetary injections through the period. This lead to both a real income boost and to faster and stronger rise in inflation in Europe relative to Asia (as shown in Figure 2, lower-left panel).[63]

[58] Under an helicopter drop where each agent gets a proportional share of a monetary injection, no frictions exist, and all agents are homogeneous, all prices would rise simultaneously and the injection would not affect real allocations. Here, the matter is different: the European agent first benefits from the injection which then is then transmitted through trade. Relative endowments are affected and end up affecting not just the aggregate price level but also relative prices and the volume and structure of trade. As the European agent gets richer, it spends more on both its own good and imports, and conversely for the Asian agent.

[59] They also differ from the idea that there was nothing in Europe that China wanted or didn't have, as set out in emperor Qinglong's well-known letter to King George.

[60] While much of the historical literature often refers to imperfect price convergence as a "disequilibrium" (this is even the case with DeVries 2003, p. 96), it is more correct to say that the lack price convergence is itself an equilibrium.

[61] We do assume, as is standard in the trade literature, a home bias, but this home bias is symmetric to both agents.

[62] For instance, Robert Allen writes: "[W]ages expressed in grams of silver were lower in China and India than in Europe. (...) This is important since it was the proximate cause of Asia's competitive advantage in textiles and luxury manufactures and was, thus, the basis for Asian-European trade in the early modern period. Why these differentials persisted for hundreds of years is an important question in international and monetary economics that must be addressed to explain the dynamics of the world economy in this period" (Allen 2005, p. 123).

[63] Notice that this fact dominates the effect on relative prices of stronger TFP growth in Europe during the early modern period, as documented by Broadberry and Gupta (2006).

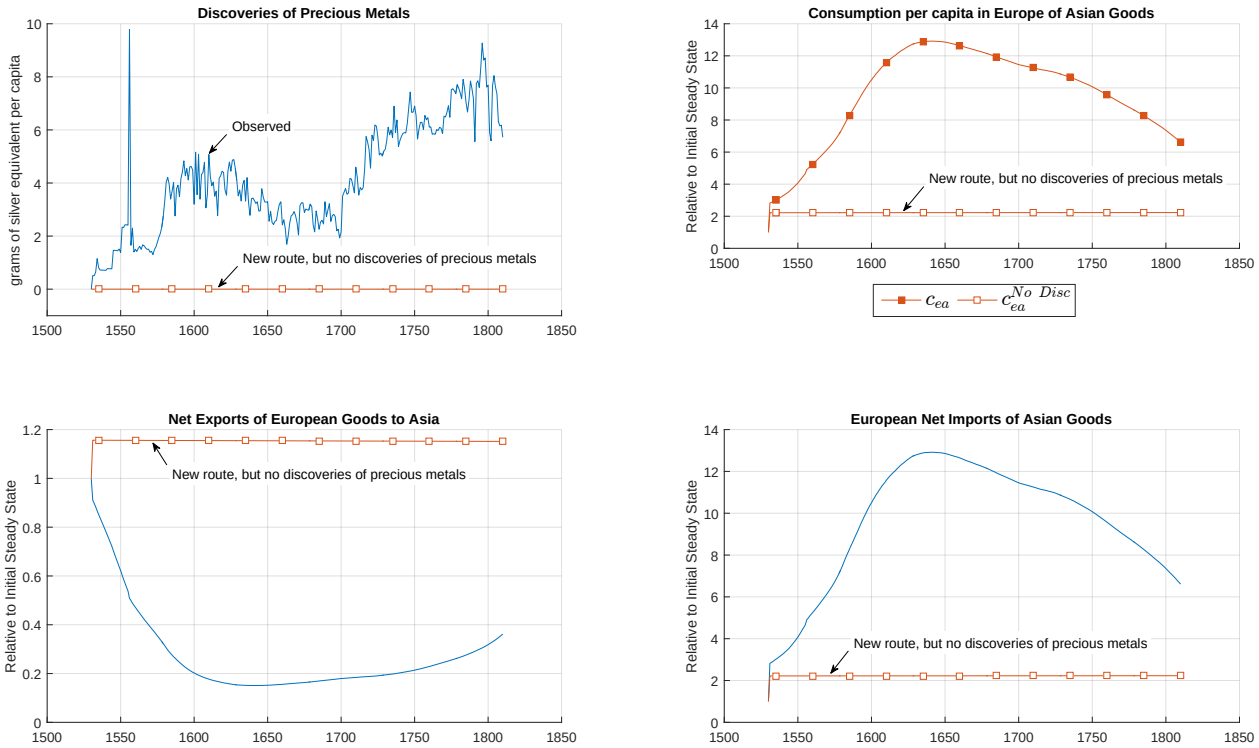


Figure 4: Comparison with the counterfactual of a discovery of a new route to Asia but no discoveries of precious metals.

We can now break down the effects of the precious metals versus those of the finding of new sea-routes to Asia. In the *Wealth of Nations*, Adam Smith wrote that "The discovery of America, and that of the passage to the East Indies by the Cape of Good Hope, are the two greatest events recorded in the history of [human] kind" (Smith 2003). But as far as explaining the volume of early modern Euro-Asian trade are concerned, what was relatively more important, the new sea-route to Asia which decreased trade transaction costs, or American precious metals? The fact that they happened almost at the same time makes it very difficult to answer this question with data alone: no control groups are available.[64] However, using our structural model allows us to answer this question by decomposing the relative contribution of each of these factors. In Figure 4, we show the counterfactual of a sea-route found to Asia ($b = b^f$), but no precious metals found in America ($d_t = 0$ for all t).[65] We can then compare the simulation with that for the historical scenario. The conclusion is that the sea-route to Asia explains at most a doubling of Euro-Asian trade in the early modern period. The effect of American precious metals is more than six times larger. [66]

[64] Furthermore, we should speak about new sea-routes rather than just one new sea route, given that the Pacific route also played a major role in transporting silver to Asia.

[65] European GDPs and population is assumed invariant to this.

[66] If the transportation costs decreased, why didn't imports of European goods by Asia increase as well? Figure 4 shows that Asian imports of European goods would have indeed increased without the windfall of precious metals. With that windfall, imports to Asia of European goods decrease to allow an increase in the imports of precious metals. In other words, not only did the new routes have a much smaller economic impact on trade than did American precious metals, but the sign of their isolated effect on trade patters was also different. This is clear if we

4 Robustness

We show that our main message is maintained if capital is added to the model, if income levels are allowed to increase, or if a plausible range of alternative parameters are used instead of our baseline choices.

4.1 Model with capital

In the baseline version of our model, money serves as a means of exchange and as the only store of value available to agents. The role of means of exchange of money is emphasized by its complementarity with consumption in equation (8). We now introduce capital, with a return higher than the return of money. The introduction of capital eliminates the need to hold money for store of value and emphasizes the role of money as a means of exchange. The European agent solves

$$\max_{c_{ee},c_{ea},k_{et},m_{et}} \sum_{t=0}^{\infty} \beta^t u\left(c_{ee}, c_{ea}, m_{et}\right) \tag{13}$$

$$\text{s.t.} \qquad p_{1t}c_{eet} + p_{2t}c_{eat}\left(1+b\right) + m_{et} + k_{et} \leq p_{1t}y_{e,t} + m_{e,t-1} + k_{e,t-1}(1-\delta) + d_t, \tag{14}$$

$$y_{e,t} = A_e f(k_{e,t-1}), \tag{15}$$

where $f(k_{e,t-1}) = A_e k_{t-1}^{\alpha}$. We assume the standard capital share of $\alpha = 0.36$. To obtain the values of A_e and A_a, we match the real income levels from Table 6. To do this, we first solve for the steady state capital levels and substitute them in the production function.[67]

The equilibrium equations are given by the first order conditions of the problem to each household's optimization problem, the budget constraints, and the market clearing conditions

$$\begin{aligned} L_e(c_{eet} + k_{et}) + L_a[c_{aet}(1+b)] &= L_e y_{e,t} + k_{e,t-1}(1-\delta), & (16)\\ L_e[c_{eat}(1+b) + L_a(c_{aat} + k_{at}) &= L_a y_{a,t} + k_{a,t-1}(1-\delta), & (17)\\ L_e m_{e,t} + L_a m_{a,t} &= L_e m_{e,t-1} + L_e d_t + L_a m_{a,t-1}. & (18) \end{aligned}$$

The model with capital implies similar results to the baseline model. Figure 5 compares the results with and without capital. European consumption of the Asian good c_{ea} peaks at about 11 times the counterfactual (no discoveries of precious metals and no new trade route) during the second quarter of the seventeenth century. It is still over 6 times the counterfactual as late as 1750. European exports of goods to Asia also remain at less than 40% of what they would have been in the absence of precious metals from the mid-sixteenth century to the mid-eighteenth century. The other per capita consumption variables (c_{ee}, c_{aa}, and c_{ae}) are close for the cases with and without capital. In the appendix, Figure A.1 shows other equilibrium values with and without capital.

look at what happens to net exports of European goods to Asia: in the counterfactual world of no precious metals existing in America, they increase.

[67] This procedure yields $A_e = y_{e,ss}^{1-\theta}\left(\frac{\theta}{1/\beta-(1-\delta)}\right)^{\frac{\theta}{1-\theta}}$ and $A_a = y_{a,ss}^{1-\theta}\left(\frac{\theta}{1/\beta-(1-\delta)}\right)^{\frac{\theta}{1-\theta}}$, where $y_{e,ss}$ and $y_{a,ss}$ are obtained from Table 6.

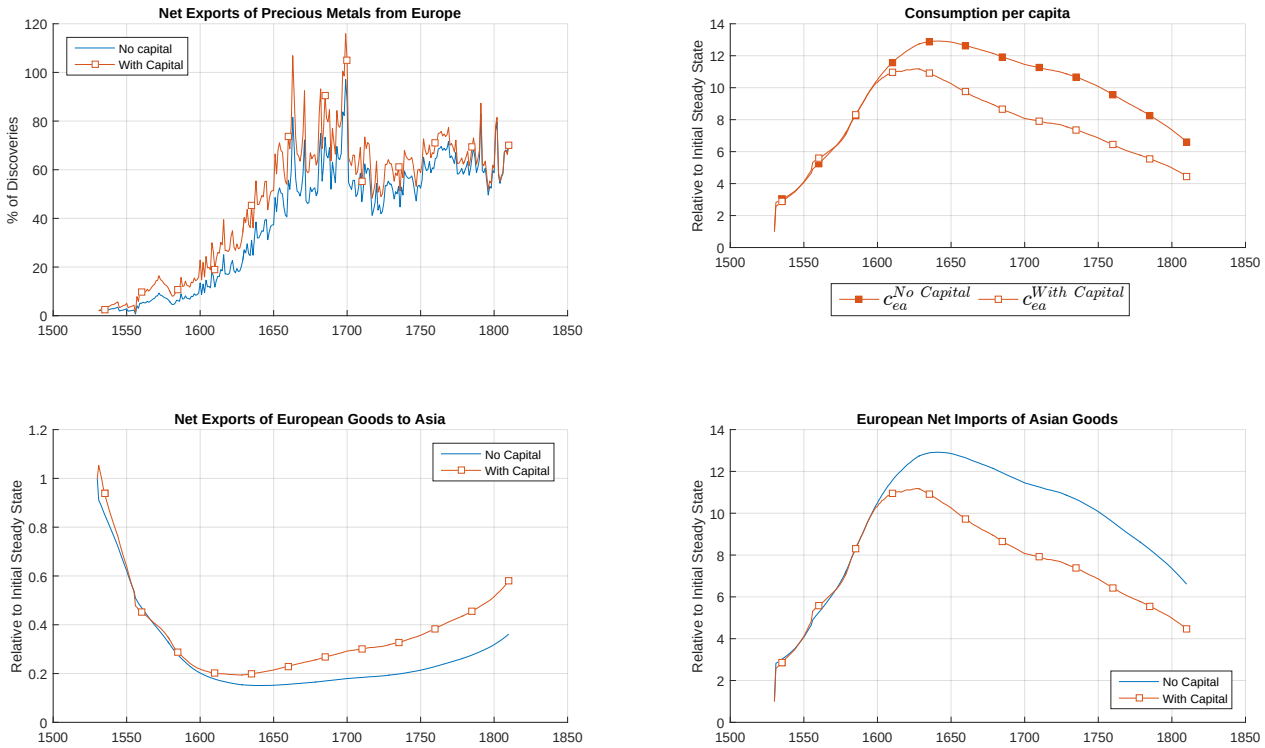


Figure 5: Simulation results with and without capital. The dynamics of the equilibrium variables are similar for both cases. In particular, the discoveries of precious metals still imply much higher consumption of Asian goods in Europe and imports of Asian goods.

Europe exports more precious metals in the model with capital (Figure 5). In Europe, capital slightly falls after the discovery of metals, as people consume more imported goods over time and invest less (Figure 6). This movement allows Europe to export more precious metals and import more Asian goods. On the other hand, to import more precious metals, Asia invests so that production increases and exports of goods increase. Capital per capita in Europe, in due time, overtakes that of Asia relatively to its initial value. As the shock is temporary (it is a windfall), the optimal solution for the Asian agent is to temporarily increase capital to increase production, export more and import more precious metals.

4.2 Increase in income per capita

The real per capita income in Europe grew from 771 GK dollars in the sixteenth century to 1204 GK dollars by the early nineteenth century, as shown in Table 6. Could the higher levels of early modern Euro-Asian trade have been primarily caused by rising incomes in Europe, rather than decreasing transportation costs or access to American precious metals?

In the baseline simulations, we used for Europe's income the sample average of 965.75 GK dollars. We now consider the same exercise as before, but keeping per capita income in Europe constant at 771 GK dollars. We also repeat the exercise with the highest level of per capita income

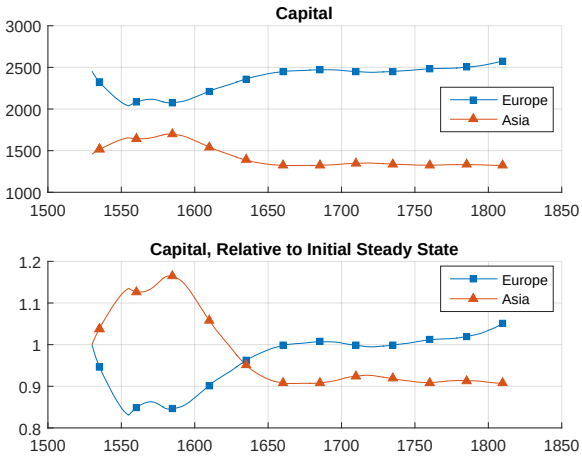


Figure 6: Dynamics of capital. Capital decreases temporarily in Europe as agents export more precious metals and import more Asian goods. Asia increases capital so that production increases and exports increase. The increase in capital allows Asia to export more goods and import more precious metals.

during the period, 1204 GK dollars.[68] For ready comparison with the baseline results, we make these exercises for the baseline model (i.e. without capital). However, as before, the results for the model with capital are similar.

Figure 7 shows the results. We concentrate on the dynamics of the net imports by Europe of Asian goods, as all variables show similar dynamics to the previous simulations. Moreover, this variable summarizes the predicted behavior of international trade after the discoveries. We obtain that an increase in Europe's per capita income increases imports of Asian goods, as predicted by DeVries (2003). However, the pattern of the dynamics and the magnitudes change little across simulations with different values of per capita income for Europe. We hence confirm that most of the increase in international trade is due to the discoveries of precious metals.

4.3 Alternative parameters

We now consider a range of alternatives for the home bias parameter ω and for the share of income spent on Asian goods, by the European agent, after the discovery of a new route to Asia and the discovery of precious metals. We consider the range of uncertainty of the share spent in Asian goods after the discoveries discussed in section 3, from 0.8% to 1.4%. The share of income before the discoveries is maintained at 0.4%. Table 9 shows the parameters considered. As before, given a value for ω, the values of b^i and b^f are chosen endogenously so that we obtain a given share of income spent on Asian goods by the European agent. We have nine sets of parameters. The

[68] Following the procedure of section 3, the parameters for the iceberg costs had to be adjusted to maintain the share of spending in Asian goods before and after the discoveries in the benchmark simulations. We obtain $b^i = 16.54$, $b^f = 7.7$ for $A_e = 771$ and $b^i = 15.66$, $b^f = 7.5$ for $A_e = 1204$. These values keep the shares of spending at 0.4% before the discoveries and 1.2% after the discoveries.

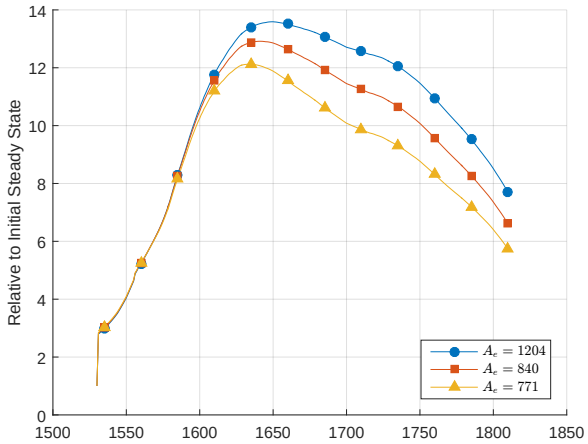


Figure 7: Net imports by Europe of Asian goods for different values of income per capita in Europe, A_e. Most of the changes in net imports are caused by the discoveries of precious metals.

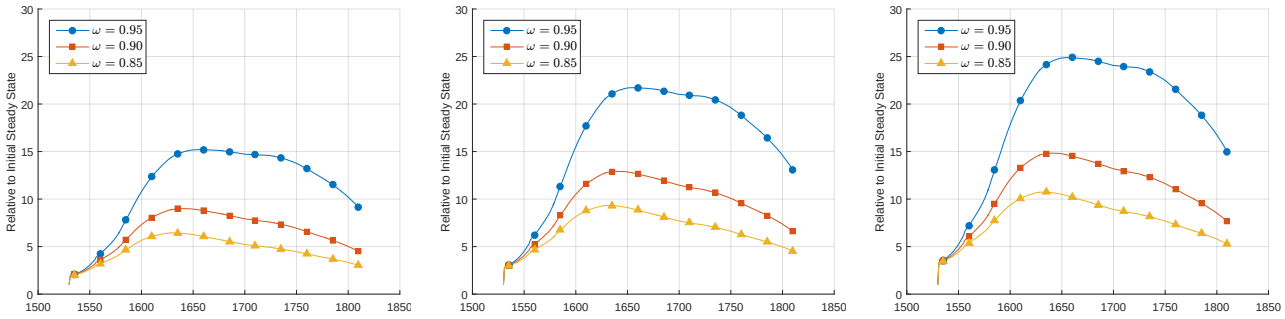
original benchmark parameters plus eight additional sets with values for the home bias and varying shares of income spent in Asian goods.

Table 9: Robustness Check—Alternative Parameters

	Share								
	0.8%			1.2%*			1.4%		
ω	0.85	0.90	0.95	0.85	0.90*	0.95	0.85	0.90	0.95
b^i	23.5	16.1	8.40	23.5	16.1*	8.40	23.5	16.1	8.40
b^f	15.67	11.15	6.17	10.812	7.61*	4.075	9.364	6.55	3.45

* Baseline. Share: share of income spent on Asian goods by the European agent after the discoveries of a new trade route and of precious metals. The share of income before the discoveries is maintained at 0.4%. Given a value for the home bias ω, the iceberg costs b^i and b^f are found to match the share of income spent on Asian goods before and after the discoveries.

The dynamics of the endogenous variables are similar for each set of parameters. We concentrate on the dynamics for net imports by Europe of Asian goods for clarity. Figure 8 shows the results. We see that increasing the home bias ω or increasing the share of income spent on Asian goods increase the impact of the discoveries. However, all simulations show the same dynamics. The peak of the increase in imports relative to the initial steady state varies from about seven times the counterfactual, for the case with $\omega = 0.85$ and a share of 0.8%, to about 25, for the case with $\omega = 0.95$ and a share equal to 1.4%. Our baseline case, with $\omega = 0.90$ and a share of 1.2% has a peak of imports relative to the initial steady state of about 13. In any case, this change in parameters do not modify our conclusion that the discoveries of precious metals had a fundamental impact for the increase in imports of Asian goods.



(a) Share: 0.8% (b) Share: 1.2% (c) Share: 1.4%

Figure 8: Robustness check. Net imports by Europe of Asian goods for different values of the share parameter and home bias ω. Share of income spent in Asian goods after the discoveries. See table 9 for the iceberg cost in each case. Baseline: $Share = 1.2\%$ and $\omega = 0.90$.

5 Conclusion

Without New World precious metals, early modern Euro-Asian trade would not have been possible in the scale that we have observed. Europeans did not produce or have access to goods that Asians were willing to purchase in significant quantities. While previous explanations for the import of precious metals into Asia typically rely on an "Asiatic inclination for hoarding," we show that the observed trade pattern can be explained using a dynamic general equilibrium model.[69]

Our results also suggest the following novel conclusions.[70] First, without European access to American precious metals, the volume of trade would have been much smaller. While this has been previously suggested qualitatively, we are able to quantify the magnitude of the effect for the first time. Under our baseline scenario, European purchases of Asian goods were up to six times what they would have been without American precious metals. Second, Asians would have a more eclectic mix of European goods, as well as a higher overall quantity of European goods if we except precious metals. To our knowledge, this has never been suggested before. Third, the finding of a sea-route to Asia was of secondary importance in explaining the growing importance of Euro-Asian trade during the early modern period. Instead, American precious metals deserve the center-stage, confirming the suspicions of economic historian Earl J. Hamilton when he wrote that "No matter how the [European] price level and domestic trade might have been maintained through monetary manipulation, commerce with the Far East could not have flourished as it did without the great supply of bullion from the New World" (Hamilton 1952).

Why should we care about early modern Euro-Asian trade? First, because it help us understand Euro-Asian trade patterns today. Our results show that monetary factors play an important

[69] Of course, cultural elements may have mattered as well. What we show is that they do not seem to be essential to understanding the patterns of Euro-Asian trade in this period.

[70] We have arrived to our conclusions using a structural model. As it is always the case with history, repeated realizations are impossible. A structural model can give us answers when confounding problems and the lack of appropriate control groups imply that no amount of new observational data would provide a firm answer about a counterfactual.

role to explain real allocations. In the period we cover, the Asia's need to have a means of payment for its large economy stimulated international trade. Today, China has large holdings of foreign assets in the form of U.S. government bonds, and understanding the source of their demand can help us understand international trade. Second, because the evidence suggests that Euro-Asian trade started off a historical dynamic process with broad consequences for Europe. While foreign trade accounted for a small percentage of European GDP at this time, it provided dynamic expansion opportunities (O'Rourke and Williamson 2002, Costa, Palma and Reis 2015).[71] Early modern trade with Asia led to the emergence of mercantile companies such as the Dutch VOC and the English East India Company, which in many ways were the prototype for modern multinationals.[72] It permitted the development of modern financial markets in Amsterdam and London (Neal 1990). It induced an industrious revolution (DeVries 2008) which encouraged additional labor input and market participation in Europe, necessary preconditions for the process of modern economic growth and for the industrial revolution itself. It stimulated economic growth and urbanization, through a process of spillovers and agglomeration economies (Allen 2009, Palma 2016a). Trading with Asia (and America), may have also induced a shift in the wealth and political power from the land-owning elite to the hands of a merchant, entrepreneurial class (Acemoglu et al 2005, Jha 2015). Positive spillovers also resulted from the increased inter-continental exchange of ideas. Finally, international trade and war always came together (Findlay and O'Rourke 2003) and in turn external warfare associated with international trade was one of the most powerful drivers behind European state-building (Besley and Persson 2008, Dincecco and Katz 2014).[73]

These facts suggest the strategic importance of Euro-Asian trade for Europe during the early modern era. Our results suggest that understanding early modern Euro-Asian trade is impossible without looking into the monetary injections of the period. This has implications for our understanding of early modern global history and the road to modern economic growth. In particular, our results contrast with those of Clark, O'Rourke, and Taylor (2008), who argue that trade with America only mattered marginally for European industrialization. They write that "Had the Americas not existed, or not been discovered, there were ready substitutes for the cotton, sugar, corn and timber of the New World in Eastern Europe, the Near East and South Asia." Our analysis suggests that this is misleading. The New World mattered because no European substitute existed for American precious metals. As we have shown, without precious metals, the import of Asian goods would have been impossible at a volume close to the observed volumes. And without the import of Asian goods to Europe, early modern history would have been different. Understanding the true impact of American precious metals for early modern Europe holds much promise in our understanding of Europe's take-off.

[71] In the three centuries covered in this paper, European mercantile companies lost an average of one life for every 4.7 tons of Asian cargo imported to Europe (DeVries 2003, p. 74). By the mid-eighteenth century, when in average each European was consuming one pound of Asian commodities, "To secure that pound (...) required six or seven thousand European lives and about 150 tons of silver each year" (DeVries 2003, p. 82). Clearly, Europeans cared a great deal about consuming Asian goods.

[72] Adam Smith recognized Asians were not interested in purchasing European goods and links the availability of precious metals to the emergence of the European mercantile companies: "The increasing consumption of East India goods in Europe is, it seems, so great, as to afford a gradual increase of employment to them [VOC, EIC and so on] all" (Smith 2003, p. 278).

[73] See Fouquet and Broadberry (2015) for a review of the evidence that suggests that most European countries went through a process of per capita GDP growth during the early modern period.

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A Appendix

A.1 Methodological notes for Table 4

First, because of differing sources, there is a difference of 1 year relative to Table 3. Second, since population levels are only available for 1500, 1600, 1700 and 1820, each figure in the two first columns is actual production divided by initial population of the period in question. Therefore, as population was growing, there is a slight upward bias in the numbers. For example, for 1500-1549, we use the 1500 levels. For the years for which no population numbers are available, the numbers are computed by using an average. For instance, for 1550-1559, the number is computed as $\frac{26.5\times10^6}{50\times(52268+73778)/2} = 8.4$. For 1750-1799, population used is that of 1820. Since population was increasing during the early 19th century, this produces a conservative estimate, as does using the initial population for each 50-year interval.

The European unskilled wage is proxied by that of a building laborer and that of a skilled laborer by a building craftsman. Because of the small size of American economies—from negligible initially to non-negligible towards the end of the period but still small relative to Europe—and because of imports through the Philippines as well as smuggling, the actual windfall may be closer to the production figures (see Pieper 2012 for evidence that this was the case). Second, there was some production in central Europe until the middle of the sixteenth century (Munro 2013), but we only consider American production. Third, Morineau's figures for Europe include only amounts across the Atlantic. But trade through the Philippines benefited European agents as well. About wage levels, the lower bound of the range is more representative, as the distribution is skewed. An example is that for the period 1600-1649, where the wage of a building craftsman in Madrid is 20.1 but the second highest observation, in Antwerp, is 12.6. More generally, the upper bound is usually representative of only one or two cities, which are special either because of nominal reasons, such as Madrid, or real reasons, such as Antwerp, Amsterdam, and London. For this reason, using the upper bound leads to a (very conservative) lower bound about the relative size of the injection. For the 1500-1549 period, such an individual earned a wage which ranged from 2.1 grams of silver per day in Augsburg to 4.2 in Valencia. If we ignore Spain, the variation is up to 3.3 in Naples (Allen 2001, p. 416). So, for these individuals, receiving 5 grams of silver in a year from the windfall would be the equivalent of what they earned in up to 2 days of work. For sure, the windfall was not equally distributed, but this calculation shows how large the silver injections really were. For the 1650-1699 period, the variation ranges from 2.7 in Warsaw to 9.7 in London.

A.2 Additional figure

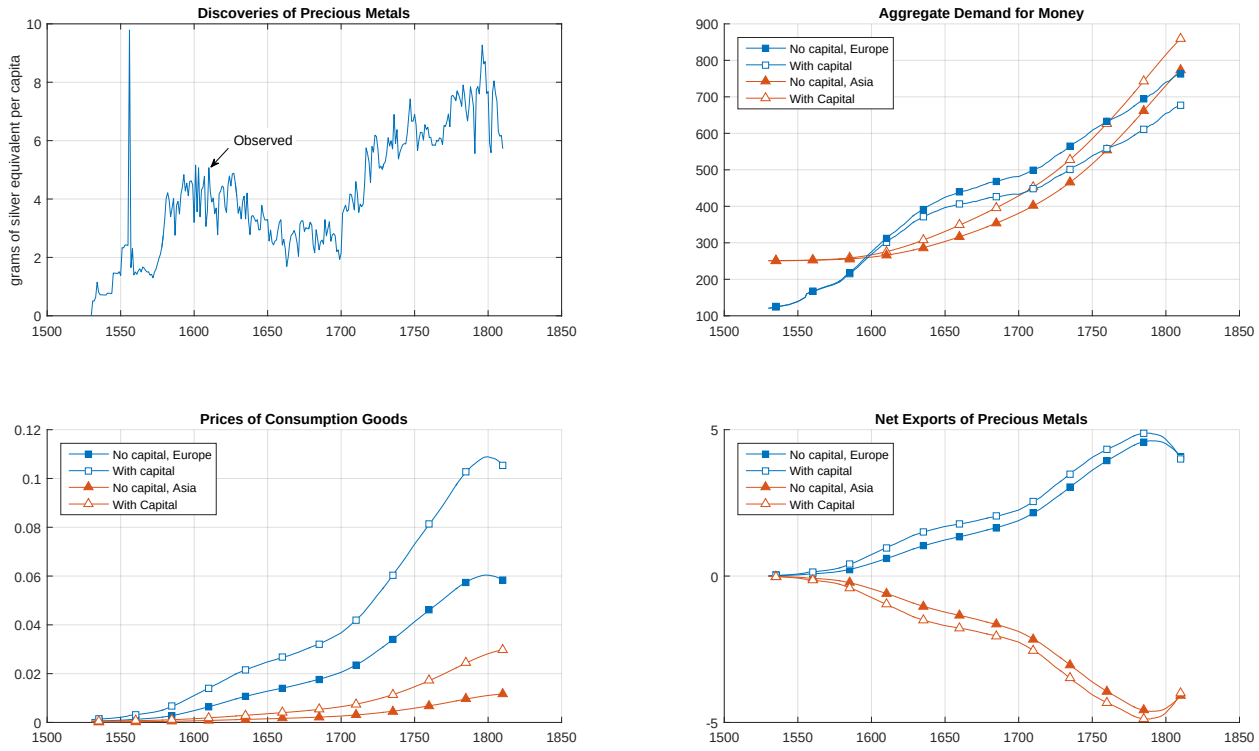


Figure A.1: Data on discoveries of precious metals and comparison of simulation results with and without capital. The case without capital is repeated from figure 2.

ONLINE APPENDIX (not for journal publication)

Mathematical results for the case with capital; the most general case of our model.
Preferences for Europe:

$$u\left(c_{et},m_{et}\right)=\frac{\left[a_{e}c_{et}^{\eta_{e}}+\left(1-a_{e}\right)m_{et}^{\eta_{e}}\right]^{\frac{1-\sigma_{e}}{\eta_{e}}}-1}{1-\sigma_{e}}, \tag{A.1}$$

where $c_{et}\equiv\left[\omega_{e}^{\frac{1}{\gamma_{e}}}c_{eet}^{\frac{\gamma_{e}-1}{\gamma_{e}}}+\left(1-\omega_{e}\right)^{\frac{1}{\gamma_{e}}}c_{eat}^{\frac{\gamma_{e}-1}{\gamma_{e}}}\right]^{\frac{\gamma_{e}}{\gamma_{e}-1}}$.

Preferences for Asia:

$$u\left(c_{at},m_{at}\right)=\frac{\left[a_{a}c_{at}^{\eta_{a}}+\left(1-a_{a}\right)m_{at}^{\eta_{a}}\right]^{\frac{1-\sigma_{a}}{\eta_{a}}}-1}{1-\sigma_{a}}, \tag{A.2}$$

where $c_{at}\equiv\left[\left(1-\omega_{a}\right)^{\frac{1}{\gamma_{a}}}c_{aet}^{\frac{\gamma_{a}-1}{\gamma_{a}}}+\omega_{a}^{\frac{1}{\gamma_{a}}}c_{aat}^{\frac{\gamma_{a}-1}{\gamma_{a}}}\right]^{\frac{\gamma_{a}}{\gamma_{a}-1}}$. These preferences reduce to the log case when $\sigma\rightarrow1$, $\eta\rightarrow0$ and $\gamma\rightarrow1$.

The optimization problem for the European agent is

$$\max_{c_{ee},c_{ea},m_{e}}\sum_{t=0}^{\infty}\beta^{t}u\left(c_{et},m_{et}\right) \tag{A.3}$$

$$\text{s.t.}\qquad p_{1t}c_{eet}+p_{2t}c_{eat}\left(1+b\right)+m_{e,t}+p_{1t}k_{e,t}\leq p_{1t}A_{e}k_{et-1}^{\theta}+m_{e,t-1}+p_{1t}\left(1-\delta\right)k_{e,t-1}+d_{t}, \tag{A.4}$$

where $p_{1t}=\dfrac{\tilde{p}_{1t}}{p_{gt}}$, $p_{2t}=\dfrac{\tilde{p}_{2t}}{p_{gt}}$, given $m_{e,-1}>0$.

Market clearing conditions:

$$L_{e}c_{eet}+L_{a}\left(1+b\right)c_{aet}+L_{e}k_{et}=L_{e}A_{e}k_{et-1}^{\theta}+L_{e}\left(1-\delta\right)k_{et-1}, \tag{A.5}$$

$$L_{e}c_{eat}\left(1+b\right)+L_{a}c_{aat}+L_{a}k_{at}=L_{a}A_{a}k_{at-1}^{\theta}+L_{a}\left(1-\delta\right)k_{at-1}, \tag{A.6}$$

$$L_{e}m_{e,t}+L_{a}m_{a,t}=L_{e}m_{e,t-1}+L_{e}d_{t}+L_{a}m_{a,t-1}. \tag{A.7}$$

Lagrangian for Europe:

$$\begin{aligned}L &= \sum_{t=0}^{\infty}\beta^{t}u\left(c_{et},m_{et}\right)+\sum_{t=0}^{\infty}\lambda_{t}(p_{1t}A_{e}k_{et-1}^{\theta}+m_{e,t-1}+p_{1t}\left(1-\delta\right)k_{e,t-1}+d_{t}- &\text{(A.8)}\\ &\quad -p_{1t}c_{eet}-p_{2t}c_{eat}\left(1+b\right)-m_{e,t}-p_{1t}k_{e,t}). &\text{(A.9)}\end{aligned}$$

Derivatives:

$$\frac{\partial u\left(c_{et},m_{et}\right)}{\partial c_{et}}=\left[a_{e}c_{et}^{\eta}+\left(1-a_{e}\right)m_{et}^{\eta}\right]^{\frac{1-\sigma-\eta}{\eta}}a_{e}c_{et}^{\eta-1}, \tag{A.10}$$

$$\frac{\partial c_{et}}{\partial c_{eet}}=\left[\omega_{e}^{\frac{1}{\gamma}}c_{eet}^{\frac{\gamma-1}{\gamma}}+\left(1-\omega_{e}\right)^{\frac{1}{\gamma}}c_{eat}^{\frac{\gamma-1}{\gamma}}\right]^{\frac{1}{\gamma-1}}\omega_{e}^{\frac{1}{\gamma}}c_{eet}^{-\frac{1}{\gamma}}=\left(\frac{c_{et}\omega_{e}}{c_{eet}}\right)^{\frac{1}{\gamma}}, \tag{A.11}$$

$$\frac{\partial c_{et}}{\partial c_{eat}}=\left[\omega_{e}^{\frac{1}{\gamma}}c_{eet}^{\frac{\gamma-1}{\gamma}}+\left(1-\omega_{e}\right)^{\frac{1}{\gamma}}c_{eat}^{\frac{\gamma-1}{\gamma}}\right]^{\frac{1}{\gamma-1}}\left(1-\omega_{e}\right)^{\frac{1}{\gamma}}c_{eat}^{-\frac{1}{\gamma}}, \tag{A.12}$$

$$\frac{\partial u\left(c_{et},m_{et}\right)}{\partial m_{et}}=\left[a_{e}c_{et}^{\eta}+\left(1-a_{e}\right)m_{et}^{\eta}\right]^{\frac{1-\sigma-\eta}{\eta}}\left(1-a_{e}\right)m_{et}^{\eta-1}. \tag{A.13}$$

The second summation in (A.8) implies

$$\begin{aligned}&...+\lambda_{t}(p_{1t}A_{e}k_{et-1}^{\theta}+m_{e,t-1}+p_{1t}\left(1-\delta\right)k_{e,t-1}+d_{t}-p_{1t}c_{eet}-p_{2t}c_{eat}\left(1+b\right)-m_{e,t}-p_{1t}k_{e,t})+ &\text{(A.14)}\\ &+\lambda_{t+1}(p_{1t+1}A_{e}k_{et}^{\theta}+m_{e,t}+p_{1t+1}\left(1-\delta\right)k_{e,t}+d_{t+1}-\\ &-p_{1t+1}c_{eet+1}-p_{2t+1}c_{eat+1}\left(1+b\right)-m_{e,t+1}-p_{1t}k_{e,t+1})+...\end{aligned}$$

First order necessary conditions:

$$[k_{et}] : \lambda_t p_{1t} = \lambda_{t+1} p_{1t+1} \left(\theta A_e k_{et}^{\theta-1} + 1 - \delta\right), \tag{A.15}$$

$$[c_{eet}] : \beta^t \frac{\partial u\left(c_{et}, m_{et}\right)}{\partial c_{et}} \frac{\partial c_{et}}{\partial c_{eet}} = \lambda_t p_{1t}, \tag{A.16}$$

$$[c_{eat}] : \beta^t \frac{\partial u\left(c_{et}, m_{et}\right)}{\partial c_{et}} \frac{\partial c_{et}}{\partial c_{eat}} = \lambda_t p_{2t} \left(1 + b\right), \tag{A.17}$$

$$[m_{et}] : \beta^t \frac{\partial u\left(c_{et}, m_{et}\right)}{\partial m_{et}} = \lambda_t + \lambda_t p_{1t} \alpha_e \left(m_{e,t} - m_{e,t-1}\right)^{\kappa_e - 1} - \lambda_{t+1}. \tag{A.18}$$

Budget constraint:

$$p_{1t} A_e k_{et-1}^{\theta} + m_{e,t-1} + p_{1t}\left(1 - \delta\right) k_{e,t-1} + d_t - p_{1t} c_{eet} - p_{2t} c_{eat}\left(1 + b\right) - m_{e,t} - p_{1t} k_{e,t} = 0. \tag{A.19}$$

Substitutions implies

$$\frac{c_{eet}}{c_{eat}} = \frac{\omega_e}{1 - \omega_e} \left(\frac{p_{2t}\left(1 + b\right)}{p_{1t}}\right)^{\gamma}, \tag{A.20}$$

$$\left(1 - a_e\right) m_{et}^{\eta - 1} = a_e c_{et}^{\eta - 1} \frac{\partial c_{et}}{\partial c_{eet}} \frac{1}{p_{1t}} - \beta \left[\frac{a_e c_{et+1}^{\eta} + \left(1 - a_e\right) m_{et+1}^{\eta}}{a_e c_{et}^{\eta} + \left(1 - a_e\right) m_{et}^{\eta}}\right]^{\frac{1 - \sigma - \eta}{\eta}} a_e c_{et+1}^{\eta - 1} \frac{\partial c_{et+1}}{\partial c_{eet+1}} \frac{1}{p_{1t+1}}, \tag{A.21}$$

$$\Rightarrow c_{et}^{\eta - 1} \frac{\partial c_{et}}{\partial c_{eet}} = c_{et+1}^{\eta - 1} \frac{\partial c_{et+1}}{\partial c_{eet+1}} \beta \left[\frac{a_e c_{et+1}^{\eta} + \left(1 - a_e\right) m_{et+1}^{\eta}}{a_e c_{et}^{\eta} + \left(1 - a_e\right) m_{et}^{\eta}}\right]^{\frac{1 - \sigma - \eta}{\eta}} \left(\theta A_e k_{et}^{\theta - 1} + 1 - \delta\right). \tag{A.22}$$

Equations (A.19)-(A.22) form a dynamic system with four equations and four endogenous variables: c_{eet}, c_{eat}, m_{et}, and k_{et}.

With similar steps for Asia, we obtain

$$p_{2t} A_a k_{at-1}^{\theta} + m_{a,t-1} + p_{1t}\left(1 - \delta\right) k_{a,t-1} - p_{1t} c_{aet}\left(1 + b\right) - p_{2t} c_{aat} - m_{a,t} - p_{2t} k_{a,t} = 0, \tag{A.23}$$

$$\frac{c_{aet}}{c_{aat}} = \frac{1 - \omega_a}{\omega_a} \left(\frac{p_{2t}}{p_{1t}\left(1 + b\right)}\right)^{\gamma}, \tag{A.24}$$

$$\begin{aligned} \left(1 - a_a\right) m_{at}^{\eta - 1} = a_a c_{at}^{\eta - 1} \frac{\partial c_{at}}{\partial c_{aat}} \frac{1}{p_{2t}} \left(1 + p_{2t} \alpha_a \left(m_{a,t} - m_{a,t-1}\right)^{\kappa_a - 1}\right) - \\ - \beta \left[\frac{a_a c_{at+1}^{\eta} + \left(1 - a_a\right) m_{at+1}^{\eta}}{a_a c_{at}^{\eta} + \left(1 - a_a\right) m_{at}^{\eta}}\right]^{\frac{1 - \sigma - \eta}{\eta}} a_a c_{at+1}^{\eta - 1} \frac{\partial c_{at+1}}{\partial c_{aat+1}} \frac{1}{p_{2t+1}} \left(1 + p_{2t+1} \alpha_a \left(m_{a,t+1} - m_{a,t}\right)^{\kappa_a - 1}\right), \end{aligned} \tag{A.25}$$

$$c_{at}^{\eta - 1} \frac{\partial c_{at}}{\partial c_{aat}} = c_{at+1}^{\eta - 1} \frac{\partial c_{at+1}}{\partial c_{aat+1}} \beta \left[\frac{a_a c_{at+1}^{\eta} + \left(1 - a_a\right) m_{at+1}^{\eta}}{a_a c_{at}^{\eta} + \left(1 - a_a\right) m_{at}^{\eta}}\right]^{\frac{1 - \sigma - \eta}{\eta}} \left(\theta A_a k_{at}^{\theta - 1} + 1 - \delta\right). \tag{A.26}$$

Again, equations (A.23)-(A.26) form a dynamic system with four equations and four endogenous variables, c_{aet}, c_{aat}, m_{at}, e k_{at}.

The steady state is obtained by setting $d_t = 0$ and looking for constant values of c_{eet}, c_{eat}, m_{et}, k_{et}, c_{aet}, c_{aat}, m_{at}, and k_{at} that satisfy the equations above. For Europe, we have

$$\frac{\partial u\left(c_e, m_e\right)}{\partial c_e} = \left[a_e c_e^{\eta_e} + \left(1 - a_e\right) m_e^{\eta_e}\right]^{\frac{1 - \sigma_e - \eta_e}{\eta_e}} a_e c_e^{\eta_e - 1}, \tag{A.27}$$

$$\frac{\partial c_e}{\partial c_{ee}} = \left[\omega_e^{\frac{1}{\gamma_e}} c_{ee}^{\frac{\gamma_e - 1}{\gamma_e}} + \left(1 - \omega_e\right)^{\frac{1}{\gamma_e}} c_{ea}^{\frac{\gamma_e - 1}{\gamma_e}}\right]^{\frac{1}{\gamma_e - 1}} \omega_e^{\frac{1}{\gamma_e}} c_{ee}^{-\frac{1}{\gamma_e}}, \tag{A.28}$$

$$\frac{\partial c_e}{\partial c_{ea}} = \left[\omega_e^{\frac{1}{\gamma_e}} c_{ee}^{\frac{\gamma_e-1}{\gamma_e}} + (1-\omega_e)^{\frac{1}{\gamma_e}} c_{ea}^{\frac{\gamma_e-1}{\gamma_e}}\right]^{\frac{1}{\gamma_e-1}} (1-\omega_e)^{\frac{1}{\gamma_e}} c_{ea}^{-\frac{1}{\gamma_e}}, \tag{A.29}$$

$$\frac{\partial u(c_e, m_e)}{\partial m_e} = \left[a_e c_e^{\eta_e} + (1-a_e) m_e^{\eta_e}\right]^{\frac{1-\sigma_e-\eta_e}{\eta_e}} (1-a_e) m_e^{\eta_e - 1}, \tag{A.30}$$

$$\frac{c_{ee}}{c_{ea}} = \frac{\omega_e}{1-\omega_e}\left(\frac{p_2(1+b)}{p_1}\right)^{\gamma_e}, \tag{A.31}$$

$$p_1 c_{ee} + p_2 c_{ea}(1+b) + p_1 \delta k_e = p_1 A_e k_e^{\theta}, \tag{A.32}$$

$$\beta^t \frac{\partial u(c_e, m_e)}{\partial m_e} = \lambda_t - \lambda_{t+1}, \tag{A.33}$$

$$\lambda_t = \beta^t \frac{\partial u(c_e, m_e)}{\partial c_e} \frac{\partial c_e}{\partial c_{ee}} \frac{1}{p_1}, \tag{A.34}$$

$$\lambda_{t+1} = \beta^{t+1} \frac{\partial u(c_e, m_e)}{\partial c_e} \frac{\partial c_e}{\partial c_{ee}} \frac{1}{p_1} \tag{A.35}$$

$$\Rightarrow \lambda_t - \lambda_{t+1} = \frac{\partial u(c_e, m_e)}{\partial c_e} \frac{\partial c_e}{\partial c_{ee}} \frac{1}{p_1} \beta^t (1-\beta), \tag{A.36}$$

$$\beta^t \frac{\partial u(c_e, m_e)}{\partial m_e} = \frac{\partial u(c_e, m_e)}{\partial c_e} \frac{\partial c_e}{\partial c_{ee}} \frac{1}{p_1} \beta^t (1-\beta), \tag{A.37}$$

$$\left[a_e c_e^{\eta} + (1-a_e) m_e^{\eta}\right]^{\frac{1-\sigma-\eta}{\eta}} (1-a_e) m_e^{\eta-1} = \left[a_e c_e^{\eta} + (1-a_e) m_e^{\eta}\right]^{\frac{1-\sigma-\eta}{\eta}} a_e c_e^{\eta-1} \frac{\partial c_e}{\partial c_{ee}} \frac{1}{p_1} (1-\beta), \tag{A.38}$$

$$m_e = c_e \left[(1-\beta) \frac{a_e}{1-a_e} \frac{\partial c_e}{\partial c_{ee}} \frac{1}{p_1}\right]^{\frac{1}{\eta_e - 1}}, \tag{A.39}$$

$$\lambda_t p_1 = \lambda_{t+1} p_1 \left(\theta A_e k_e^{\theta-1} + 1 - \delta\right). \tag{A.40}$$

With the expressions of λ_t and λ_{t+1}, we obtain $1 = \beta\left(\theta A_e k_e^{\theta-1} + 1 - \delta\right)$ and so

$$k_e = \left(\frac{\theta A_e}{1/\beta - (1-\delta)}\right)^{1/(1-\theta)}. \tag{A.41}$$

GDP in Europe is given by $y_e = A_e k_e^{\theta} \Rightarrow y_e = A_e^{\frac{1}{1-\theta}} \left(\frac{\theta}{1/\beta-(1-\delta)}\right)^{\theta/(1-\theta)}$. Therefore, $y_e = \bar{y} \Leftrightarrow A_e = \bar{y}^{1-\theta} \left(\frac{\theta}{1/\beta-(1-\delta)}\right)^{-\theta}$. We calibrate A_e so that $y_{ss}^I = A_e$. Note that capital, and so GDP, are independent of the discoveries of precious metals.

For Asia, similar calculations lead to

$$k_a = \left(\frac{\theta A_a}{1/\beta - (1-\delta)}\right)^{1/(1-\theta)}. \tag{A.42}$$

The market clearing conditions are given by

$$L_e c_{ee} + L_a c_{ae}(1+b) + L_e k_{et} = L_e A_e k_{et-1}^{\theta} + L_e(1-\delta) k_{et-1}, \tag{A.43}$$

$$L_e c_{ea}(1+b) + L_a c_{aa} + L_a k_{at} = L_a A_a k_{at-1}^{\theta} + L_a(1-\delta) k_{at-1}, \tag{A.44}$$

$$L_e m_e + L_a m_a = L_e m_e + L_a m_a. \tag{A.45}$$

The last of which is trivially satisfied. We then have 10 variables, c_{ee}, c_{ae}, c_{ea}, c_{aa}, p_1, p_2, m_e, m_a, k_e, and k_a, and 10 equations.

Let $u_{et} \equiv \left(a_e c_{et}^{\eta_e} + (1-a_e)\, m_{et}^{\eta_e}\right)$, $u_{at} \equiv \left(a_a c_{at}^{\eta_a} + (1-a_a)\, m_{at}^{\eta_a}\right)$, $c_e \equiv \left[\omega_e^{\frac{1}{\gamma_e}} c_{ee}^{1-\frac{1}{\gamma_e}} + (1-\omega_e)^{\frac{1}{\gamma_e}} c_{ea}^{1-\frac{1}{\gamma_e}}\right]^{\frac{1}{1-1/\gamma_e}}$, $c_a \equiv \left[(1-\omega_a)^{\frac{1}{\gamma_a}} c_{ae}^{\frac{\gamma_a-1}{\gamma_a}} + \omega_a^{\frac{1}{\gamma_a}} c_{aa}^{\frac{\gamma_a-1}{\gamma_a}}\right]^{\frac{1}{1-1/\gamma_a}}$. Therefore,

$$\frac{\partial c_e}{\partial c_{ee}} = \left[\omega_e^{\frac{1}{\gamma_e}} c_{ee}^{\frac{\gamma_e-1}{\gamma_e}} + (1-\omega_e)^{\frac{1}{\gamma_e}} c_{ea}^{\frac{\gamma_e-1}{\gamma_e}}\right]^{\frac{1}{\gamma_e-1}} \omega_e^{\frac{1}{\gamma_e}} c_{ee}^{-\frac{1}{\gamma_e}} = \left(\frac{c_e \omega_e}{c_{ee}}\right)^{\frac{1}{\gamma_e}} \tag{A.46}$$

$$\Rightarrow \left(\frac{\partial c_e}{\partial c_{ee}}\right)^{\gamma_e} c_{ee} = c_e \omega_e, \tag{A.47}$$

$$\frac{\partial c_a}{\partial c_{aa}} = \left[(1-\omega_a)^{\frac{1}{\gamma_a}} c_{ae}^{\frac{\gamma_a-1}{\gamma_a}} + \omega_a^{\frac{1}{\gamma_a}} c_{aa}^{\frac{\gamma_a-1}{\gamma_a}}\right]^{\frac{1}{\gamma_a-1}} \omega_a^{\frac{1}{\gamma_a}} c_{aa}^{-\frac{1}{\gamma_a}} = \left(\frac{c_a \omega_a}{c_{aa}}\right)^{\frac{1}{\gamma_a}} \tag{A.48}$$

$$\Rightarrow \left(\frac{\partial c_a}{\partial c_{aa}}\right)^{\gamma_e} c_{aa} = c_a \omega_a. \tag{A.49}$$

In our code, the endogenous variables are expressed in natural logarithm. Hence, every value of the low case letters refers to the natural log of the corresponding variable. For instance, c_t refers to $\log C_t$ where C_t is the level of consumption as previously represented. The values of the derivatives are with respect to the level of consumption, C_t. The equations for the dynare code are shown below.

The budget constraint for Europe is given by

$$P_{1t} C_{eet} + P_{2t} C_{eat}\,(1+b) + M_{e,t} + P_{1t} K_{e,t} = P_{1t} A_e K_{et-1}^{\theta} + M_{e,t-1} + P_{1t}\,(1-\delta)\, K_{e,t-1} + d_t \tag{A.50}$$

$$\Rightarrow e^{p_{1t}+c_{eet}} + e^{\log(1+b)+p_{2t}+c_{eat}} + e^{m_{e,t}} + e^{p_{1t}+k_{et}} = e^{\log A_e + p_{1t} + \theta k_{et-1}} + e^{m_{e,t-1}} + e^{p_{1t}+\log(1-\delta)+k_{e,t-1}} + d_t. \tag{A.51}$$

The other conditions are

$$C_{eet}\,(1-\omega_e)\, P_{1t}^{\gamma_e} = C_{eat} \omega_e \left(P_{2t}\,(1+b)\right)^{\gamma_e} \tag{A.52}$$

$$\Rightarrow \log(1-\omega_e) + c_{eet} + \gamma_e p_{1t} = \log \omega_e + \gamma_e \log(1+b) + c_{eat} + \gamma_e p_{2t},$$

$$(1-a_e)\, M_{et}^{\eta-1} = a_e C_{et}^{\eta-1} \frac{\partial C_{et}}{\partial C_{eet}} \frac{1}{P_{1t}} - \beta \left[\frac{a_e C_{et+1}^{\eta} + (1-a_e)\, M_{et+1}^{\eta}}{a_e C_{et}^{\eta} + (1-a_e)\, M_{et}^{\eta}}\right]^{\frac{1-\sigma-\eta}{\eta}} a_e C_{et+1}^{\eta-1} \frac{\partial C_{et+1}}{\partial C_{eet+1}} \frac{1}{P_{1t+1}}, \tag{A.53}$$

$$\Rightarrow \left(a_e \left(\frac{M_{et}}{C_{et}}\right)^{1-\eta_e} \left(\frac{\omega_e C_{et}}{C_{eet}}\right)^{\frac{1}{\gamma_e}} - P_{1t}\,(1-a_e)\right) P_{1t+1} u_{et+1}^{\frac{\eta_e+\sigma_e-1}{\eta_e}} = a_e \beta \left(\frac{M_{et}}{C_{et+1}}\right)^{1-\eta_e} \left(\frac{\omega_e C_{et+1}}{C_{eet+1}}\right)^{\frac{1}{\gamma_e}} P_{1t} u_{et}^{\frac{\eta_e+\sigma_e-1}{\eta_e}} \tag{A.54}$$

$$\begin{aligned} \Rightarrow \quad & \log\left(a_e e^{(1-\eta_e)(m_{et}-c_{et}) + \frac{1}{\gamma_e}(\log\omega_e + c_{et} - c_{eet})} - (1-a_e)\, e^{p_{1t}}\right) + p_{1t+1} + \left(\tfrac{\eta_e+\sigma_e-1}{\eta_e}\right) \log u_{et+1} \qquad \text{(A.55)} \\ = \quad & \log(a_e\beta) + (1-\eta_e)\,(m_{et} - c_{et+1}) + \frac{1}{\gamma_e}\left(\log\omega_e + c_{et+1} - c_{eet+1}\right) + p_{1t} + \left(\tfrac{\eta_e+\sigma_e-1}{\eta_e}\right) \log u_{et} \end{aligned}$$

$$\begin{aligned} \Rightarrow \quad & \left(a_e e^{(1-\eta_e)(m_{et}-c_{et}) + \frac{1}{\gamma_e}(\log\omega_e + c_{et} - c_{eet})} - (1-a_e)\, e^{p_{1t}}\right) \exp\left(p_{1t+1} + \left(\tfrac{\eta_e+\sigma_e-1}{\eta_e}\right) \log u_{et+1}\right) \qquad \text{(A.56)} \\ = \quad & a_e\beta \exp\left((1-\eta_e)\,(m_{et} - c_{et+1}) + \frac{1}{\gamma_e}\left(\log\omega_e + c_{et+1} - c_{eet+1}\right) + p_{1t} + \left(\tfrac{\eta_e+\sigma_e-1}{\eta_e}\right) \log u_{et}\right). \end{aligned}$$

Also,

$$C_{et}^{\eta-1}\frac{\partial C_{et}}{\partial C_{eet}}=C_{et+1}^{\eta-1}\frac{\partial C_{et+1}}{\partial C_{eet+1}}\beta\left[\frac{a_eC_{et+1}^{\eta}+(1-a_e)M_{et+1}^{\eta}}{a_eC_{et}^{\eta}+(1-a_e)M_{et}^{\eta}}\right]^{\frac{1-\sigma-\eta}{\eta}}\left(\theta A_eK_{et}^{\theta-1}+1-\delta\right). \tag{A.57}$$

Using $\frac{1-\sigma-\eta}{\eta}=-\frac{\eta+\sigma-1}{\eta}$, $\frac{\partial c_{et}}{\partial c_{eet}}=\left(\frac{c_{et}\omega_e}{c_{eet}}\right)^{\frac{1}{\gamma}}$, and $u_{et}=a_eC_{et}^{\eta_e}+(1-a_e)M_{et}^{\eta_e}$, equation (A.57) can be simplified to

$$C_{et+1}^{1-\eta}\left(\frac{C_{et}}{C_{eet}}\right)^{\frac{1}{\gamma}}=C_{et}^{1-\eta}\left(\frac{C_{et+1}}{C_{eet+1}}\right)^{\frac{1}{\gamma}}\beta\left(\frac{u_{et}}{u_{et+1}}\right)^{-\frac{\eta+\sigma-1}{\eta}}\left(\theta A_eK_{et}^{\theta-1}+1-\delta\right) \tag{A.58}$$

$$\Rightarrow e^{(1-\eta)c_{et+1}}e^{\frac{1}{\gamma}(c_{et}-c_{eet})}=e^{(1-\eta)c_{et}}e^{\frac{1}{\gamma}(c_{et+1}-c_{eet+1})}e^{\log\beta}e^{-\frac{\eta+\sigma-1}{\eta}(\log u_{et}-\log u_{et+1})}\left(e^{\log\theta+\log A_e+(\theta-1)k_{et}}+e^{\log(1-\delta)}\right) \tag{A.59}$$

$$\Rightarrow e^{(1-\eta)c_{et+1}+\frac{1}{\gamma}(c_{et}-c_{eet})}=e^{(1-\eta)c_{et}+\frac{1}{\gamma}(c_{et+1}-c_{eet+1})+\log\beta-\frac{\eta+\sigma-1}{\eta}(\log u_{et}-\log u_{et+1})}\left(e^{\log\theta+\log A_e-(1-\theta)k_{et}}+e^{\log(1-\delta)}\right). \tag{A.60}$$

For Asia, we have

$$P_{1t}C_{aet}(1+b)+P_{2t}C_{aat}+M_{a,t}+P_{2t}K_{a,t}=P_{2t}A_aK_{at-1}^{\theta}+M_{a,t-1}+P_{2t}(1-\delta)K_{a,t-1} \tag{A.61}$$

$$\Rightarrow e^{\log(1+b)+p_{1t}+c_{aet}}+e^{p_{2t}+c_{aat}}+e^{m_{a,t}}+e^{p_{2t}+k_{at}}=e^{\log A_a+p_{2t}+\theta k_{at-1}}+e^{m_{a,t-1}}+e^{p_{2t}+\log(1-\delta)+k_{at-1}}.$$

Consumption

$$\frac{C_{aet}}{C_{aat}}=\frac{1-\omega_a}{\omega_a}\left(\frac{P_{2t}}{P_{1t}(1+b)}\right)^{\gamma_a} \tag{A.62}$$

$$\Rightarrow\log\omega_a+\gamma_a\log(1+b)+c_{aet}+\gamma_ap_{1t}=\log(1-\omega_a)+c_{aat}+\gamma_ap_{2t}.$$

We also have

$$\begin{aligned}(1-a_a)M_{at}^{\eta-1} &= a_aC_{at}^{\eta-1}\tfrac{\partial C_{at}}{\partial C_{aat}}\tfrac{1}{P_{2t}}\left(1+P_{2t}\alpha_a\left(M_{a,t}-M_{a,t-1}\right)^{\kappa_a-1}\right)- \\ &\quad-\beta\left[\tfrac{a_aC_{at+1}^{\eta}+(1-a_a)M_{at+1}^{\eta}}{a_aC_{at}^{\eta}+(1-a_a)M_{at}^{\eta}}\right]^{\frac{1-\sigma-\eta}{\eta}}a_aC_{at+1}^{\eta-1}\tfrac{\partial C_{at+1}}{\partial C_{aat+1}}\tfrac{1}{P_{2t+1}}\left(1+P_{2t+1}\alpha_a\left(M_{a,t+1}-M_{a,t}\right)^{\kappa_a-1}\right)\end{aligned} \tag{A.63}$$

$$\Rightarrow\left(a_a\left(\tfrac{M_{at}}{C_{at}}\right)^{1-\eta_a}\left(\tfrac{\omega_aC_{at}}{C_{aat}}\right)^{\frac{1}{\gamma_a}}-P_{2t}(1-a_a)\right)P_{2t+1}u_{at+1}^{\frac{\eta_a+\sigma_a-1}{\eta_a}}=a_a\beta\left(\tfrac{M_{at}}{C_{at+1}}\right)^{1-\eta_a}\left(\tfrac{\omega_aC_{at+1}}{C_{aat+1}}\right)^{\frac{1}{\gamma_a}}P_{2t}u_{at}^{\frac{\eta_a+\sigma_a-1}{\eta_a}} \tag{A.64}$$

$$\begin{aligned}\Rightarrow &\quad\left(a_ae^{(1-\eta_a)(m_{at}-c_{at})+\frac{1}{\gamma_a}(\log\omega_a+c_{at}-c_{aat})}-(1-a_a)e^{p_{2t}}\right)\exp\left(p_{2t+1}+\left(\tfrac{\eta_a+\sigma_a-1}{\eta_a}\right)\log u_{at+1}\right) \\ = &\quad a_a\beta\exp\left((1-\eta_a)(m_{at}-c_{at+1})+\frac{1}{\gamma_a}(\log\omega_a+c_{at+1}-c_{aat+1})+p_{2t}+\left(\tfrac{\eta_a+\sigma_a-1}{\eta_a}\right)\log u_{at}\right),\end{aligned} \tag{A.65}$$

and

$$C_{at}^{\eta-1}\frac{\partial C_{at}}{\partial C_{aat}}=C_{at+1}^{\eta-1}\frac{\partial C_{at+1}}{\partial C_{aat+1}}\beta\left[\frac{a_aC_{at+1}^{\eta}+(1-a_a)M_{at+1}^{\eta}}{a_aC_{at}^{\eta}+(1-a_a)M_{at}^{\eta}}\right]^{\frac{1-\sigma-\eta}{\eta}}\left(\theta A_aK_{at}^{\theta-1}+1-\delta\right). \tag{A.66}$$

With $\frac{1-\sigma-\eta}{\eta}=-\frac{\eta+\sigma-1}{\eta}$, $\frac{\partial c_{at}}{\partial c_{aat}}=\left(\frac{c_{at}\omega_a}{c_{aat}}\right)^{\frac{1}{\gamma}}$, $u_{at}=a_aC_{at}^{\eta_a}+(1-a_a)M_{at}^{\eta_a}$, we obtain

$$C_{at}^{\eta-1}\left(\frac{C_{at}\omega_a}{C_{aat}}\right)^{\frac{1}{\gamma}}=C_{at+1}^{\eta-1}\left(\frac{C_{at+1}\omega_a}{C_{aat+1}}\right)^{\frac{1}{\gamma}}\beta\left(\frac{u_{at}}{u_{at+1}}\right)^{-\frac{\eta+\sigma-1}{\eta}}\left(\theta A_aK_{at}^{\theta-1}+1-\delta\right) \tag{A.67}$$

$$\Rightarrow e^{(1-\eta)c_{at+1}+\frac{1}{\gamma}(c_{at}-c_{aat})}=e^{(1-\eta)c_{at}+\frac{1}{\gamma}(c_{at+1}-c_{aat+1})+\log\beta-\frac{\eta+\sigma-1}{\eta}(\log u_{at}-\log u_{at+1})}\left(e^{\log\theta+\log A_a-(1-\theta)k_{at}}+e^{\log(1-\delta)}\right). \tag{A.68}$$

Market clearing condition for European goods:

$$L_eC_{eet}+L_aC_{aet}\left(1+b\right)+L_eK_{et}=L_eA_eK_{et-1}^{\theta}+L_e\left(1-\delta\right)K_{et-1} \tag{A.69}$$

$$\Rightarrow e^{\log L_e+c_{eet}}+e^{\log L_a+\log(1+b)+c_{aet}}+e^{\log L_e+k_{et}}=e^{\log L_e+\log A_e+\theta k_{et-1}}+e^{\log L_e+\log(1-\delta)+k_{et-1}}. \tag{A.70}$$

For Asian Goods

$$L_ec_{eat}\left(1+b\right)+L_ac_{aat}+L_aK_{at}=L_aA_aK_{at-1}^{\theta}+L_a\left(1-\delta\right)K_{at-1} \tag{A.71}$$

$$\Rightarrow e^{\log L_e+\log(1+b)+c_{eat}}+e^{\log L_a+c_{aat}}+e^{\log L_a+k_{at}}=e^{\log L_a+\log A_a+\theta k_{at-1}}+e^{\log L_a+\log(1-\delta)+k_{at-1}}. \tag{A.72}$$

For money

$$L_eM_{e,t}+L_aM_{a,t}=L_e\left(M_{e,t-1}+d_t\right)+L_aM_{a,t-1} \tag{A.73}$$

$$\Rightarrow e^{\log L_e+m_{e,t}}+e^{\log L_a+m_{a,t}}=e^{\log L_e+m_{e,t-1}}+L_ed_t+e^{\log L_a+m_{a,t-1}}. \tag{A.74}$$

We have ten endogenous variables, p_{1t}, p_{2t}, c_{eet}, c_{eat}, m_{et}, k_{et}, c_{aet}, c_{aat}, m_{at}, k_{at}, and ten equations. One market clearing condition is redundant.

Let

$$u_{et}\equiv a_eC_{et}^{\eta_e}+\left(1-a_e\right)M_{et}^{\eta_e}\Rightarrow u_{et}=a_ee^{\eta_ec_{et}}+\left(1-a_e\right)e^{\eta_em_{et}}, \tag{A.75}$$

$$u_{at}\equiv a_aC_{at}^{\eta_a}+\left(1-a_a\right)M_{at}^{\eta_a}\Rightarrow u_{at}=a_ae^{\eta_ac_{at}}+\left(1-a_a\right)e^{\eta_am_{at}}, \tag{A.76}$$

$$C_e\equiv\left[\omega_e^{\frac{1}{\gamma_e}}C_{ee}^{1-\frac{1}{\gamma_e}}+\left(1-\omega_e\right)^{\frac{1}{\gamma_e}}C_{ea}^{1-\frac{1}{\gamma_e}}\right]^{\frac{1}{1-1/\gamma_e}}\Rightarrow e^{(1-1/\gamma_e)c_e}=e^{\frac{1}{\gamma_e}\log\omega_e+\left(1-\frac{1}{\gamma_e}\right)c_{ee}}+e^{\frac{1}{\gamma_e}\log(1-\omega_e)+\left(1-\frac{1}{\gamma_e}\right)c_{ea}}, \tag{A.77}$$

$$C_a\equiv\left[\left(1-\omega_a\right)^{\frac{1}{\gamma_a}}C_{ae}^{\frac{\gamma_a-1}{\gamma_a}}+\omega_a^{\frac{1}{\gamma_a}}C_{aa}^{\frac{\gamma_a-1}{\gamma_a}}\right]^{\frac{1}{1-1/\gamma_a}}\Rightarrow e^{(1-1/\gamma_a)c_a}=e^{\frac{1}{\gamma_a}\log(1-\omega_a)+\left(1-\frac{1}{\gamma_a}\right)c_{ae}}+e^{\frac{1}{\gamma_a}\log\omega_a+\left(1-\frac{1}{\gamma_a}\right)c_{aa}}. \tag{A.78}$$

Therefore, $\frac{\partial C_e}{\partial C_{ee}}=\left[\omega_e^{\frac{1}{\gamma_e}}C_{ee}^{\frac{\gamma_e-1}{\gamma_e}}+\left(1-\omega_e\right)^{\frac{1}{\gamma_e}}C_{ea}^{\frac{\gamma_e-1}{\gamma_e}}\right]^{\frac{1}{\gamma_e-1}}\omega_e^{\frac{1}{\gamma_e}}C_{ee}^{-\frac{1}{\gamma_e}}=\left(\frac{C_e\omega_e}{C_{ee}}\right)^{\frac{1}{\gamma_e}}\Rightarrow\left(\frac{\partial C_e}{\partial C_{ee}}\right)^{\gamma_e}C_{ee}=\omega_eC_e$

$$\Rightarrow\frac{\partial C_e}{\partial C_{ee}}=\exp\left(\frac{\log\omega_e+c_e-c_{ee}}{\gamma_e}\right). \tag{A.79}$$

$$\frac{\partial C_a}{\partial C_{aa}}=\left[\left(1-\omega_a\right)^{\frac{1}{\gamma_a}}C_{ae}^{\frac{\gamma_a-1}{\gamma_a}}+\omega_a^{\frac{1}{\gamma_a}}C_{aa}^{\frac{\gamma_a-1}{\gamma_a}}\right]^{\frac{1}{\gamma_a-1}}\omega_a^{\frac{1}{\gamma_a}}C_{aa}^{-\frac{1}{\gamma_a}}=\left(\frac{C_a\omega_a}{C_{aa}}\right)^{\frac{1}{\gamma_a}}\Rightarrow\left(\frac{\partial C_a}{\partial C_{aa}}\right)^{\gamma_e}C_{aa}=\omega_aC_a$$

$$\Rightarrow\frac{\partial C_a}{\partial C_{aa}}=\exp\left(\frac{\log\omega_a+c_a-c_{aa}}{\gamma_e}\right). \tag{A.80}$$

Steady state. In the steady state, the budget constraint for Europe is given by

$$P_1C_{ee}+P_2C_{ea}\left(1+b\right)+P_1\delta K_e=P_1A_eK_e^{\theta} \tag{A.81}$$

$$\Rightarrow e^{p_1+c_{ee}}+e^{\log(1+b)+p_2+c_{ea}}+e^{p_1+\log\delta+k_e}=e^{p_1+\log A_e+\theta k_e}. \tag{A.82}$$

Consumption in Europe follows

$$\log(1-\omega_e) - \log\omega_e - \gamma_e \log(1+b) + c_{ee} + \gamma_e p_1 - c_{ea} - \gamma_e p_2 = 0 \tag{A.83}$$

Money and consumption in Europe satisfy

$$\begin{aligned}&\left(a_e e^{(1-\eta_e)(m_{et}-c_{et})+\frac{1}{\gamma_e}(\log\omega_e+c_{et}-c_{eet})} - (1-a_e)\, e^{p_{1t}}\right)\exp\left(p_{1t+1} + \left(\tfrac{\eta_e+\sigma_e-1}{\eta_e}\right)\log u_{et+1}\right) = \\ &= a_e\beta\exp[(1-\eta_e)(m_{et}-c_{et+1}) + \frac{1}{\gamma_e}(\log\omega_e + c_{et+1} - c_{eet+1}) + p_{1t} + \left(\tfrac{\eta_e+\sigma_e-1}{\eta_e}\right)\log u_{et}]\end{aligned} \tag{A.84}$$

$$\Rightarrow a_e e^{(1-\eta_e)(m_e-c_e)} e^{\frac{1}{\gamma_e}(\log\omega_e+c_e-c_{ee})} - (1-a_e)\, e^{p_1} - a_e\beta e^{(1-\eta_e)(m_e-c_e)} e^{\frac{1}{\gamma_e}(\log\omega_e+c_e-c_{ee})} = 0 \tag{A.85}$$

$$a_e(1-\beta)\, e^{(1-\eta_e)(m_e-c_e)+\frac{1}{\gamma_e}(\log\omega_e+c_e-c_{ee})} - (1-a_e)\, e^{p_1} = 0 \tag{A.86}$$

$$\Rightarrow \log a_e - \log(1-a_e) + \log(1-\beta) + (1-\eta_e)(m_e-c_e) + \frac{1}{\gamma_e}(\log\omega_e + c_e - c_{ee}) - p_1 = 0 \tag{A.87}$$

For capital in Europe in the steady state, we have

$$K_{et} = \left(\frac{\theta A_e}{1/\beta - (1-\delta)}\right)^{\frac{1}{1-\theta}} \Rightarrow k_{et} = \frac{1}{1-\theta}\log\left(\frac{\theta A_e}{1/\beta-(1-\delta)}\right). \tag{A.88}$$

Consumption in Asia in the steady state must satisfy

$$\log(1-\omega_a) - \log\omega_a - \gamma_a\log(1+b) + c_{aa} + \gamma_a p_2 - c_{ae} - \gamma_a p_1 = 0. \tag{A.89}$$

Money and consumption in Asia follow

$$\begin{aligned}&\left(a_a e^{(1-\eta_a)(m_{at}-c_{at})+\frac{1}{\gamma_a}(\log\omega_a+c_{at}-c_{aat})} - (1-a_a)\, e^{p_{2t}}\right)\exp\left(p_{2t+1} + \left(\tfrac{\eta_a+\sigma_a-1}{\eta_a}\right)\log u_{at+1}\right) \\ = \;& a_a\beta\exp[(1-\eta_a)(m_{at}-c_{at+1}) + \frac{1}{\gamma_a}(\log\omega_a + c_{at+1} - c_{aat+1}) + p_{2t} + \left(\tfrac{\eta_a+\sigma_a-1}{\eta_a}\right)\log u_{at}]\end{aligned} \tag{A.90}$$

$$\Rightarrow e^{\log a_a + \log(1-\beta) + (1-\eta_a)(m_a-c_a) + \frac{1}{\gamma_a}(\log\omega_a+c_a-c_{aa})} = e^{\log(1-a_a)+p_2} \tag{A.91}$$

$$\Rightarrow \log a_a - \log(1-a_a) + \log(1-\beta) + (1-\eta_a)(m_a-c_a) + \frac{1}{\gamma_a}(\log\omega_a + c_a - c_{aa}) - p_2 = 0. \tag{A.92}$$

For capital in Asia in the steady state, we have

$$K_{at} = \left(\frac{\theta_a A_a}{1/\beta-(1-\delta)}\right)^{\frac{1}{1-\theta_a}} \Rightarrow k_{at} = \frac{1}{1-\theta_a}\log\left(\frac{\theta_a A_a}{1/\beta-(1-\delta)}\right). \tag{A.93}$$

The market clearing conditions for European Goods, Asian Goods, and precious metals in the steady state imply

$$e^{\log L_e + \log A_e + \theta k_e} - e^{\log L_e + c_{ee}} - e^{\log L_a + \log(1+b) + c_{ae}} - e^{\log L_e + \log\delta + k_e} = 0, \tag{A.94}$$

$$e^{\log L_a + \log A_a + \theta k_a} - e^{\log L_e + \log(1+b) + c_{ea}} - e^{\log L_a + c_{aa}} - e^{\log L_a + \log\delta + k_a} = 0, \tag{A.95}$$

$$\begin{aligned}M^S - e^{\log L_e + m_e} &= 0, \\ M^S - e^{\log L_e + m_e} - e^{\log L_a + m_a} &= 0.\end{aligned} \tag{A.96}$$

Also, in the steady state,

$$u_{et} = a_e e^{\eta_e c_e} + (1 - a_e)\, e^{\eta_e m_e}, \tag{A.97}$$

$$u_{at} = a_a e^{\eta_a c_a} + (1 - a_a)\, e^{\eta_a m_a}. \tag{A.98}$$

The composite good for Europe in the steady state is given by $C_e \equiv \left[\omega_e^{\frac{1}{\gamma_e}} C_{ee}^{1-\frac{1}{\gamma_e}} + (1-\omega_e)^{\frac{1}{\gamma_e}} C_{ea}^{1-\frac{1}{\gamma_e}}\right]^{\frac{1}{1-1/\gamma_e}}$

$$\Rightarrow (1 - 1/\gamma_e)\, c_e - \log\left(e^{\frac{1}{\gamma_e}\log\omega_e + (1-1/\gamma_e)c_{ee}} + e^{\frac{1}{\gamma_e}\log(1-\omega_e) + (1-1/\gamma_e)c_{ea}}\right) = 0. \tag{A.99}$$

For Asia, $C_a \equiv \left[(1-\omega_a)^{\frac{1}{\gamma_a}} C_{ae}^{\frac{\gamma_a - 1}{\gamma_a}} + \omega_a^{\frac{1}{\gamma_a}} C_{aa}^{\frac{\gamma_a - 1}{\gamma_a}}\right]^{\frac{1}{1-1/\gamma_a}}$

$$\Rightarrow (1 - 1/\gamma_a)\, c_a - \log\left(e^{\frac{1}{\gamma_a}\log(1-\omega_a) + (1-1/\gamma_a)c_{ae}} + e^{\frac{1}{\gamma_a}\log\omega_a + (1-1/\gamma_a)c_{aa}}\right) = 0. \tag{A.100}$$

Moreover, $\frac{\partial C_e}{\partial C_{ee}} = \left[\omega_e^{\frac{1}{\gamma_e}} C_{ee}^{\frac{\gamma_e - 1}{\gamma_e}} + (1-\omega_e)^{\frac{1}{\gamma_e}} C_{ea}^{\frac{\gamma_e - 1}{\gamma_e}}\right]^{\frac{1}{\gamma_e - 1}} \omega_e^{\frac{1}{\gamma_e}} C_{ee}^{-\frac{1}{\gamma_e}} = \left(\frac{C_e \omega_e}{C_{ee}}\right)^{\frac{1}{\gamma_e}} \Rightarrow \left(\frac{\partial C_e}{\partial C_{ee}}\right)^{\gamma_e} C_{ee} = \omega_e C_e$

$$\Rightarrow \frac{\partial C_e}{\partial C_{ee}} - \exp\left(\frac{\log\omega_e + c_e - c_{ee}}{\gamma_e}\right) = 0. \tag{A.101}$$

And $\frac{\partial C_a}{\partial C_{aa}} = \left[(1-\omega_a)^{\frac{1}{\gamma_a}} C_{ae}^{\frac{\gamma_a - 1}{\gamma_a}} + \omega_a^{\frac{1}{\gamma_a}} C_{aa}^{\frac{\gamma_a - 1}{\gamma_a}}\right]^{\frac{1}{\gamma_a - 1}} \omega_a^{\frac{1}{\gamma_a}} C_{aa}^{-\frac{1}{\gamma_a}} = \left(\frac{C_a \omega_a}{C_{aa}}\right)^{\frac{1}{\gamma_a}} \Rightarrow \left(\frac{\partial C_a}{\partial C_{aa}}\right)^{\gamma_e} C_{aa} = \omega_a C_a$

$$\Rightarrow 0 = \frac{\partial C_a}{\partial C_{aa}} - \exp\left(\frac{\log\omega_a + c_a - c_{aa}}{\gamma_e}\right). \tag{A.102}$$