Beneath the Gold Points: European Financial Market Integration, 1844-1870*

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June 17, 2015

Abstract

We apply threshold-regression analysis to a new database of exchange rates and bullion prices covering five top European financial centers before the gold standard (1844-1870). We confirm the finding in the literature that TAR-estimated thresholds are systematically smaller than historically observed gold points. To rationalize this puzzle, we review the assumptions of the classical gold-point arbitrage model and conclude that TAR-computed thresholds cannot be interpreted as transaction costs in the bullion trade. High integration may be explained not by low transaction costs in bilateral bullion arbitrage, but by availability of multilateral financial arbitrage techniques.

Keywords: Financial integration, efficiency, exchange rate, gold points, TAR model.

JEL: N23, F3, G15.

* This paper has benefited from comments and discussions by Olivier Accominotti, Pamfili Antipa, François Bourguignon, Régis Breton, Christophe Chamley, David Chilosi, Rui Esteves, Giovanni Federico, Cecilia Garcia-Peñalosa, Clemens Jobst, Pilar Nogues, Angelo Riva, Alan Taylor, François Velde, as well as participants to presentations in Aix-en-Provence, Antwerp, London, and Paris. The views expressed here are those of the authors and not necessarily those of the Bank of France or the Eurosystem.

1. Introduction

The *classical gold-point arbitrage model* model argues that adjustment within the international commodity-based monetary system occurs through bilateral flows of the metal into which domestic currencies are convertible.[2] Bullion flows are supposed to occur whenever the exchange rate exceeds the thresholds determined by the transaction costs of moving metal – usually known as the gold (or silver) points. In a context of full capital mobility across countries, the width of the band within which the exchange rate can float *without* triggering bullion shipments has therefore been seen as an indicator of the degree of financial integration. In this analytical framework, the efficiency of the international monetary system has been judged by its ability to trigger bullion flows whenever the exchange rate reach the gold points (see e.g. Einzig, 1929; Morgenstern, 1959; Officer, 1986, 1996). This definition of efficiency has prompted scholars to estimate gold points in order to check whether financial markets were integrated – i.e., whether bullion flows actually followed depreciation or appreciation of nominal exchange rates.

Two main approaches have been developed to measure the size of the gold points. The direct approach consists of calculating transaction costs from historical sources (see e.g. Einzig, 1929; Officer, 1996; Flandreau, 1996; Esteves et al., 2007). The results of these investigations have sparked a large debate,[3] notably on one specific historical case: the dollar-sterling market during the classical gold standard period (1873-1914). Morgenstern (1959) and Clark (1984) argued that the gold standard was inefficient because gold arbitrage did not take place when the exchange rate lied outside of the band. Officer (1986, 1996) computed new estimates of the transaction costs of moving gold between New York and London to restore the efficiency view of the gold standard. Other scholars have developed an indirect approach by developing econometric techniques on exchange rate data series to estimate the threshold above/below which exchange rate series displayed a mean-reverting behavior. The intuition for this is as follows: in a deficit country, the price of bills of exchange must stop appreciating when agents start using gold or silver (instead of bills) for their international payments; therefore, mean-reversion occurs for the exchange rate when appreciation stops. Pioneered by Obstfeld and Taylor (1997), the application of threshold autoregressive (TAR) models to price data has been

[2] Unlike Hume's (1752) price-specie-flow mechanism model, the classical gold-point arbitrage model is actually a partial equilibrium one – focusing on the international purchasing power parity of gold in terms of *currency*, not on international purchasing power parity of gold in terms of *all traded commodities*. Marcuzzo and Rosselli (1987) explain that the reason is that the international equalization of general price levels is a sufficient, but not a necessary condition for gold arbitrage to stop.

[3] Defining which *specific* transaction cost actually matters in a given period is difficult, and measuring it is tricky: for instance, think of the difficulty in measuring the monetary benefit of speedier transport technologies. Another problem consists of finding of the historical documentation and constructing complete time series of the evolution of those transaction costs.

considered as an efficient method to measure mean-reverting processes.[4] Canjels et al. (2004) have extended their application to the classical gold-point arbitrage model.[5] In so doing, however, they have also uncovered a puzzle: the thresholds estimated with this technique for the London-New York bilateral exchange relationship were considerably smaller than the transaction costs accurately computed by Officer (1996) on the basis of extensive historical research.[6] Canjels et al. (2004) imputed this remarkable discrepancy to the faults of primary sources, but they failed to establish convincingly that historical evidence was systematically inaccurate. Hence, the puzzle remains unsolved: do indirect strategies for measuring transaction costs always point to a higher degree of financial integration than direct ones? And if so, why is that the case?

In this paper, we provide an answer to these questions. First, we apply the same empirical strategy as Canjels et al. (2004) to a different historical context: we perform threshold-regression analysis to twenty-one bilateral exchange relationships between five European financial centers that did not have credibility problems on the exchange market (London, Paris, Amsterdam, Hamburg, and Frankfurt-am-Main) during the quarter of century preceding the advent of the classical gold standard. This period is particularly appropriate in order to test techniques for measuring financial integration, as it was an epoch in which major advances in communication technologies (most notably, the introduction of telegraphic and railway lines) were put into place. In so doing, we find that Canjels at al.'s (2004) result – viz. that estimated transaction costs are much lower than the ones reported by historical sources – is a systematic outcome of threshold-regression analysis. As a second step, thus, we propose an explanation of this puzzling result. We review the assumptions of the classical gold-point arbitrage model, and argue that some of them are too restrictive to correspond to the actual workings of credible commodity-based monetary systems. In the light of this, we conclude that econometrically computed thresholds cannot be interpreted as estimates of gold points (i.e., transaction costs in the bullion trade). We suggest that exchange rate volatility was indeed kept low by international arbitrage, but that such an arbitrage was of a different nature than the one envisaged by the classical gold-point arbitrage model. Overall, our results also show that European market integration among the European core was much more pronounced than what was previously thought. Using another measure of integration, Obstfeld and Taylor (2004) argued that deep integration only started with the gold standard because it decreased the cost of international arbitrage. By contrast, our

[4] Here we only discuss univariate analyses; for a multivariate regression analysis, see e.g. Bernholz and Kugler (2011). An early example of the indirect approach to measuring transaction costs is Spiller and Wood (1988), who used a probabilistic model and concluded that transaction costs were very volatile under the classical gold standard.

[5] The influential paper by Canjels at al. (2004) has established a new branch of the historical literature. Followers include Volckart and Wolf (2006), Esteves et al. (2007), Chilosi and Volckart (2011), Li (2012), and Nogues and Herranz (2015).

[6] Note that also Esteves et al. (2007) got the very same result for the London-Lisbon bilateral exchange relationship under the gold standard: TAR-estimated thresholds were smaller than the transaction costs computed on the basis of historical sources.

results show that recourse to fiduciary payment instruments such as bills of exchange and multilateral arbitrage across currencies with very few risk of devaluation had already produced very deep integration in mid-19th-century Europe.

The rest of the paper is organized as follows. The next section illustrates the theoretical foundations of the application of threshold-regression analysis to the study of financial integration in commodity-based monetary systems. Section 3 presents our empirical methodology, Section 4 our data, and Section 5 our results. In Section 6 we discuss the question of how to interpret the outcomes of threshold-regression analysis, and suggest a new interpretation which goes beyond the limits of the classical gold-point arbitrage model. Section 7 concludes.

2. Analytical Framework

In this Section we discuss the analytical framework adopted by the literature in order to measure financial market integration under commodity-based monetary systems. First, we point out that this framework rests on a number of restrictive assumptions – something that is not generally put forward by its users. Second, we point out that one must be careful in selecting the correct price series for computing arbitrage opportunities: microstructural issues suggest that albeit often exploited by the literature, mint prices are not the right data to use in order to properly assess financial integration.

2.1. The Gold-Point Arbitrage Model

Samuelson's model of price arbitrage is the cornerstone supporting the application of the threshold-regression approach to the measuring of market integration (Samuelson, 1952). In this model, agents arbitrage price differentials away between two locations, when the price differential between the two markets is large enough to compensate for the transaction cost of moving goods across locations. Formally this can be written as

$$-C_{G,t}^{B,A} \leq X_{G,t}^{A,B} \leq C_{G,t}^{A,B} \qquad (1)$$

where $C_{G,t}^{B,A}$ is the transaction cost associated with physically transferring good G from location B to location A at time *t*, $C_{G,t}^{A,B}$ is the transaction cost associated with physically transferring G from A to B, while $X_{G,t}^{A,B}$ is the nominal price margin between A and B of commodity G, defined as

$$X_{G,t}^{A,B} = P_{G,t}^{B} \frac{P_{MB,t}^{A}}{P_{MB,t}^{B}} - P_{G,t}^{A} \qquad (2),[7]$$

where $P_{G,t}^{A}$ is the price of G in A, $P_{G,t}^{B}$ is the price of G in B, and $P_{MB,t}^{A}/P_{MB,t}^{B}$ is the nominal exchange rate – defined as the ratio of the unitary price in A of the asset MB used as money in B ($P_{MB,t}^{A}$) and the unitary price in B of the asset MB used as money there ($P_{MB,t}^{B} = 1$). $-C_{G,t}^{A,B}$ and $C_{G,t}^{B,A}$ are known as the (respectively) lower and upper commodity points (Obstfeld and Taylor, 1997).

In papers measuring commodity market integration, the model described by Equations (1) and (2) is interpreted as saying that for a given level of the nominal exchange rate $P_{MB,t}^{A}/P_{MB,t}^{B}$, fluctuations of the real exchange rate $P_{G,t}^{A}/P_{G,t}^{B}$ are constrained by the commodity points: whenever $P_{G,t}^{A}/P_{G,t}^{B}$ gets too low, a commodity flow from A to B intervenes to restore equilibrium. However, the model can well be read the other way round, viz. as saying that for a given level of the real exchange rate, fluctuations of the nominal exchange rate are constrained by the very same commodity points: whenever $P_{MB,t}^{A}/P_{MB,t}^{B}$ gets too high, a financial flow from B to A intervenes to restore equilibrium. The idea is that every commodity flow from A to B is always matched by an equal and opposite financial flow from B to A, allowing the arbitrageur to repatriate profits and hence to close the operation. The counterpart to the nominal price margin of commodity G between A and B ($X_{G,t}^{A,B}$), therefore, is the real price margin of the monetary asset MB between B and A ($X_{MB,t}^{B,A}$), defined as

$$X_{MB,t}^{B,A} = P_{MB,t}^{A} - P_{MB,t}^{B} \frac{P_{G,t}^{A}}{P_{G,t}^{B}} \qquad (3).[8]$$

The model described by Equations (1) and (3) is the actual analytical framework that has generally been adopted in order to measure financial integration under commodity-based monetary systems (see e.g. Canjels et al., 2004). Under a regime such as the gold standard, gold flows are expected to impact not the price of gold, but the nominal exchange rate: by modifying the profitability of gold arbitrage, fluctuations of the exchange rate are hence seen as the determinant of gold flows across locations. Note that as $P_{MB,t}^{B} = 1$, $X_{MB,t}^{B,A}$ is equivalent to the deviation of the nominal exchange rate from the real exchange rate (i.e. from the metallic par). Threshold-regression analysis can thus be applied to this framework: the intuition is that the price margin (the exchange rate deviation from the metallic par) will follow a random walk within the band constrained by the commodity points (the gold points), while it will converge back towards the band once its bounds are violated (Hansen 2011).

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[7] Differently said, this is the gross nominal profit of arbitraging good G from A to B (selling price minus buying price) for an agent located in A.

[8] Differently said, this is the gross real profit of arbitraging the monetary asset MB from B to A (selling price minus buying price) for an agent located in A. This is equal to the gross nominal profit of arbitraging commodity G from A to B, divided by the price of the commodity: $X_{MB,t}^{B,A} = X_{G,t}^{A,B}\left(P_{MB,t}^{B}/P_{G,t}^{B}\right)$.

It is worth underlining that the arbitrage model presented above only works under three assumptions. The first one is *bilaterality*: only what happens in the two considered locations (A and B) can have an impact on the nominal exchange rate. The second one is *non-substitutability of the arbitraged good*: only flows of the considered commodity (G) can have an impact on the nominal exchange rate – or differently said, the only relevant real exchange rate is the ratio of the prices of G ($P^A_{G,t}/P^B_{G,t}$).[9] The third one is *strict coincidence between commodity and financial flows*: financial flows can only exist as a simultaneous counterpart to commodity flows – or differently said, the commodity market (where G is exchanged) and the currency market (where MB is exchanged) are but the two sides of the same coin.[10]

Following Canjels et al. (2004), we are also going to use Equations (1) and (3) as the input of our empirical analysis. Before we do that, however, another crucial question needs to be discussed: what is the actual commodity price we should take as P_G in a commodity-based monetary system? As we shall see in Section 2.2, the answer is not as self-evident as it might appear at first sight.

2.2. What Price? The Microstructure of Bullion Markets in Europe (1844-1870)

In a commodity money system, bullion is special because it is both a commodity valued for its own sake and because of its "moneyness" (or, liquidity). It trades freely on local markets, but it can also be traded with privileged organizations (such as banks of issue, giro banks, or mints) at a regulated price. So far, the dominant view in the literature has been that under monetary regimes such as the gold standard, the price of bullion was set by such organizations, and not by traders on the market.[11] The main rationale that has been put forward is that, abstracting from transaction costs, the trading operated by those organizations was sufficient to make the legal ratio equal to the market price – or differently said, that the bullion market was fully internalized by them. Historical evidence, however, suggests that bullion markets were *not* fully internalized by official organizations, as external bullion market *did* exist.[12] As a result, understanding the microstructure of bullion markets is crucial in order to select the correct price series to compute price differentials across countries. In this section, we show that in the historical context on which we focus, arbitrageurs had a better deal on

[9] This reflects that fact that, as already pointed out, the gold-point arbitrage model is a *partial* equilibrium model.
[10] This is encapsulated by Canjels et al.'s (2004, p. 872) Equation 2, which explicitly sets changes in the stock of foreign currency domestically held as determined by gold flows.
[11] See e.g. Morgenstern (1959), Officer (1986), Spiller and Wood (1988), or Canjels et al. (2004) to quote but a few. An exception is Flandreau (1996).
[12] We confine the argument to the most developed European financial centers of the time. We concede that the situation might have been different in peripheral countries like e.g. Portugal (Esteves et al., 2007) or Spain (Nogues and Herranz, 2015).

local (external) markets than at the privileged organizations, so that the market price of bullion is the relevant price to study arbitrage relations across countries.

Before the 1870s, the currencies of all five European financial centers in our sample were on a gold monometallic, silver monometallic, or bimetallic foot. In Paris, private agents had the right to ask the mint to coin both metals; in London, the level of the legal ratio made it profitable to coin only gold, while only silver was minted in Amsterdam[13] and Frankfurt; Hamburg, which was on the silver standard, did not however have a mint. Except for Hamburg, regulated organizations did not intervene directly and in unlimited quantity on the market to set price. Rather, they were only ready to exchange bullions for local money, but at a cost and with delays. Some institutional complementarity between markets and organizations followed. Markets allowed traders to secure the benefit of the immediacy, while regulated organizations acted as market-makers offering limit prices (Ugolini, 2013). The transaction cost associated with trading with organizations generated a non-negligible price difference, while delays impeded any meaningful short-term stabilizing role of the legal ratio on the market price. This varying spread between the legal and the market price proves that arbitrageurs generally resorted to markets for implementing their operations. The rest of this section shows the historical relevance of this argument.

In each financial center, three types of regulated organizations could have been operated: 1) a mint, 2) a giro bank, or 3) a bank of issue. 1) Mints were in charge of transforming bullion into the local variety of coins, but they did not sell ingots. This means that the mint price was a bid price, not an ask price. A mint was operated in all centers in our sample except Hamburg. 2) Giro banks issued bank money against deposit of bullion. As they did not have any obligation to convert bank money into local coins, they could hence change their bid price and an ask price for bullion at their will. The only giro bank still surviving at this date was in Hamburg. 3) Banks of issue issued banknotes against local coins, and were committed to reimburse them in local coins. This means that they while their bid and ask prices for bullion could not diverge too much from the mint price, they could anyway be changed at their will according to market conditions (Ugolini, 2013). Banks of issue were active in all centers in our sample except Hamburg. Hence, each regulated organization decided the terms of the exchange of coins against metallic bars or any other means of payment such as banknotes or deposits. Only in Hamburg did the bank buy and sell silver to its depositors on demand and at a fixed price, thus anchoring the mark banco on this metal (Seyd, 1868, p. 316). Elsewhere, neither the mints nor the banks intervene on local gold or silver markets in order to put the market price in line with the official parity.

[13] To be precise, until 1847 the Netherlands were *de jure* on a bimetallic standard, but the Utrecht mint was not obliged to buy bullion at a fixed price. On that year, the country switched to silver monometallism and the mint became committed to buy silver at the official mint price (Vrolik, 1853).

Not only were regulated organizations not a viable source for buying bullion (except in Hamburg); most often, they were also an inconvenient outlet for selling it. Table 1 displays the average market price together with the legal ratio (the official bid price of the mint) and the spread between them for the five financial markets in our sample between 1844 and 1870 (see Section 4 for details). All prices are for 1 kilogram of pure alloy in terms of local money. These results look paradoxical at first sight. For instance, in Frankfurt the bid price of a kilogram of silver was 105 gulden at the mint and 104.49 on the market. The same is true for the other cities, except in Hamburg where the spread was nil. The average spread was substantial, leveling at 0.4% in Frankfurt, 0.33% in Paris and 1.14% in Amsterdam. Spreads on gold were lower but substantial too, leveling at 0.16% in London and 0.23% in Paris. The comparison is unaffected by the use of the median, suggesting that the difference is an enduring feature of those markets. The reason why market bid prices could stay systematically lower than official ones is that arbitrageurs had to face substantial transaction costs while trying to sell their bullion to them.

Table 1 about here

Selling bullion to a mint or a bank to transform it into local currency was costly both in time and money. European mints charged buyers fees for the minting of coins. The cheapest mint was the London mint that charged nothing for the production fee *but* asked the buyer to pay the cost of assaying the quality of the metal and to bring a value in gold of at least £20,000. But the highest cost for an arbitrageur was surely that the mint price was not a spot price but a price for future delivery. In London, bullion providers have to wait at least 14 days to obtain the proceeds in coins, thus losing the corresponding interest (Seyd, 1868, p. 158). In Paris, the period between the deposit of the ingots at the mint and the delivery of the coins lasted 10 days and the cost of minting was 0.21875%.[14] A more convenient way to sell the gold might have been to use the services of bank of issue that exchanged ingots for banknotes. The Banque de France charged 0.1% for a trade of banknotes against gold (Haupt, 1882, p. 410). Also the Bank of England dealt with bullion or foreign coins, the (in)convenience of which was described by Seyd (1868) as follows:

> "A stranger unacquainted with the modus operandi comes to the Bank, and offers Gold Bars for sale; he will be told, at the Bullion Office, that these Bars must first be re-melted, by the authorised Bank melters. The addresses of these being given him, he must proceed to one of them, to have the Bars remelted. The Bars are there casts into what is called the *Bank of England shape* (…). They may now be taken back to the Bullion Office. Here they are weighed in the Gold scales, the mark and weight of each Bar being called out for mutual noting. The Porters then cut off the Assay pieces, after which the Bars are trucked into the vaults. If an

[14] Haupt (1882, p. 413) wrote that the Paris mint issued a certificate in exchange for gold (the so-called "mint bill") that allowed retrieving coins after a lag, and that could be discounted on the money market. The corresponding loss of interest should therefore to be taken into account to compute the profit from arbitrage when the mint was involved in the operation.

advance of money be there and then required, the chief of the office, roughly estimating the fineness and value of the Gold from the appearance of the Bars, will authorize a payment on account, to within 5 to 10 per cent. of such estimated value. (…). A day or a couple of days after the Assays come in, and the account is got ready. The calculations are verified, the balance due is settled and paid, and the transaction is closed. The seller pays for the Assays."

Seyd (1868, p. 243).

It is therefore reassuring that there is little historical evidence that, on those markets, the actual arbitrage took place *via* the mint price: unsurprisingly, investment manuals advised investors to use the market to secure the provision of metals (e.g. Tate, 1868; Seyd, 1868). We conclude that market prices are the only relevant data series that should be used in order to compute arbitrage opportunities across our five core financial centers. As a result, the price margin that we are going to analyze is the deviation of the nominal exchange rate not from the *official* metallic par (the ratio of mint prices), but from the *arbitrated* metallic par (the ratio of market prices: Tate, 1868).

3. Econometric Specification of the TAR Model

The threshold autoregressive (TAR) model was first proposed by Tong (1978) and further developed by Tong and Lim (1980) and Tong (1983).[15] A special (or restricted) case of TAR, called the Band-TAR model, has been applied to the estimation of the transaction costs that limit price arbitrage across markets. Within the band defined by the transaction costs, agents do not arbitrage. Outside the band, unexploited profit will trigger arbitrage, which triggers a reversion of the price to the interior the band. A simple version of such Band-TAR model may be written as:

$$\Delta x_t = \begin{cases} \rho^{out}(x_{t-1} - c^{up}) + \varepsilon_t^{out} & if \quad x_{t-1} > c^{up} \\ \rho^{in} x_{t-1} + \varepsilon_t^{in} & if \quad c^{low} \le x_{t-1} \le c^{up} \\ \rho^{out}(x_{t-1} - c^{low}) + \varepsilon_t^{out} & if \quad x_{t-1} < c^{low} \end{cases} \tag{4}$$

where x_t is the *percent* exchange rate deviation from the arbitrated metallic par (the deviation being defined as in Equation (3) but divided by the par to facilitate international comparison), c^{up} (c^{low}) is the upper (lower) threshold which capture the *percent* level of arbitrage cost, ε_t^{out} is N(0, σ_{out}^2), ε_t^{in} is N(0, σ_{in}^2), and ρ^{out} (ρ^{in}) is the adjustment speed outside (inside) the thresholds of arbitrage (or inaction). The latter depends on structural elements of the economy and on nonlinear components of arbitrage costs (due e.g. to possible risk-aversion by traders). The threshold and the speed of adjustment are supposed to provide a measure of the degree of integration of two markets: the lower the arbitrage costs were and the less time the adjustment process took, the better integrated were the

[15] See Hansen (2011) for a selective review of the application of TAR models in empirical economics.

two markets (i.e. ρ^{out} will be zero in case of no integration, and negative in case of perfect integration).[16]

Theory predicts that within the band formed by thresholds there is no arbitrage, which means no price (i.e. exchange rate) adjustment when the gross profit from arbitrage is smaller than transaction costs. This theoretical property implies that the exchange rate deviation from the metallic par will follow a random walk within the gold points. We assume that $c^{up} = c^{low} = c$, implying symmetric transaction costs. We impose unit root behavior inside the band by restricting ρ^{in} to zero to increase identification of the parameters. Moreover, we assume the same error terms and conditional variance inside and outside the band. When c is known, simple least-squares methods can be applied to each subset of the data partitioned by the band (or the two thresholds). In the absence of prior knowledge about the threshold, we can still estimate this model via a grid search of all possible values of the threshold variable (here x_{t-1}),[17] which either minimizes the sum of squared residuals or maximizes the log-likelihood function of the model. As in Obstfeld and Taylor (1997), we use the maximum likelihood estimation to estimate the following equation, a restrictive version of equation (4):

$$\Delta x_t = \begin{cases} \rho^{out}(x_{t-1} - c) + \varepsilon_t^{out} & if \quad c < x_{t-1} \\ \varepsilon_t^{in} & if \quad -c \le x_{t-1} \le c \\ \rho^{out}(x_{t-1} + c) + \varepsilon_t^{out} & if \quad x_{t-1} < -c \end{cases} \qquad (5)$$

The likelihood function of equation (5) has the following form:

$$L(\rho^{out}, \sigma^{out}, \sigma^{in}; c) = -\sum_{I_{in}(x_{t-1})=1} \frac{1}{2}(\log(2\pi) + \log(\sigma^{in^2}) + \varepsilon_t^{in^2} / \sigma^{in^2}) - \sum_{I_{out}(x_{t-1})=1} \frac{1}{2}(\log(2\pi) + \log(\sigma^{out^2}) + \varepsilon_t^{out^2} / \sigma^{out^2}),$$

where $I_{in}(x_{t-1}) = I(|x_{t-1}| \le c)$ and $I_{out}(x_{t-1}) = I(|x_{t-1}| > c)$ are indicator functions which depend on the position of x_{t-1} being inside or outside the band.

For each deviation of the exchange rate to its par, we start by analyzing the stationary or unit-root analysis of the exchange deviations using the NP test developed by Ng and Perron (2001) or the

[16] Jacks (2005) takes market integration as a process with two separate but related developments: namely the articulation of a system of price convergence and adjustment.

[17] It is undesirable for a threshold value to be selected with too few observations into one or the other regime. This possibility can be excluded by restricting the search to values of threshold variable such that a minimal percentage of the observations lie in each regime (Hansen, 1999). Following Rapach and Wohar (2006), we require each regime (outer or inner) to contain at least 15% of the observations for the threshold variable.

KPSS test developed by Kwiatkowski et al. (1992) for different sub-periods.[18] If the series is detected as non-stationary (or unit root is detected), it indicates that the deviations are persistent and there is neither a mean reverting process, nor a process of returning to the edge of the band.

We estimate a TAR model when the series are stationary and run a threshold test as a test of specification to check the adequacy of the TAR alternative relative to the AR null. Because the threshold is not defined under the null, the log likelihood ratio does not follow the standard $\chi 2$ distribution, and the standard inference is invalid. Following Obstfeld and Taylor (1997) and Hansen (1999) we solve this problem using Monte Carlo simulation to derive the critical value of the test.[19] If the AR null is rejected, the estimated threshold is interpreted as the cost of arbitrage between the two locations. If the AR null cannot be rejected, this means that the deviation returns to its mean immediately, something that we interpret as the absence of cost to arbitrage. In both cases, the "half-life" of the deviation measures the time taken for the series to return to half of its initial value when it moves outside the band. It is calculated by inputting the autoregressive coefficient ρ^{out} in $\ln(0.5)/\ln(1+\rho^{out})$.[20] We interpret a low (high) half-life as a high (low) speed of the correction toward the mean (in the AR case) or towards the threshold (TAR case).

4. Data

We use a newly-collected database of spot exchange rates and bullion prices. The starting date is July 20, 1844. The start date corresponds to the Bank of England's adoption of modern discount policy following the adoption of Peel's Act. The last available quote is October 1, 1870, but in most markets quotations are discontinued several weeks before this date because of the interruption of trade triggered by the Franco-Prussian war. Following 19th-century practice, the spot exchange rate $P_{MB,t}^{A}$ is defined as the price of a bill of exchange in city A for a payment to be delivered at sight in city B in local currency. Sight bills were typically issued by private banks and were payable upon presentation to the accepting bank in the foreign city. Bills were denominated in the currency of the city on which they were drawn: for instance, bills on London sold in Amsterdam were payable in sterling upon presentation to the London address specified on the bill.

[18] Following Obstfeld and Taylor (1997), the exchange rate deviation is demeaned so as to center the series on zero. This is motivated by the idea that transaction costs may not be symmetrical in all cases as hypothesized. As we discuss below, the fact that the series are not always centered on the metallic par may be due to other reasons than asymmetric costs to bullion arbitrage (see Section 6.1).

[19] More precisely we estimate and fit an AR(1) null model on the actual data and use the estimated parameters to simulate the fitted linear model. The TAR model for each simulated series is then estimated and we calculate the corresponding Log-Likelihood Ratio. The empirical distribution of the LLR is then tabulated and used as an inference to judge the alternative TAR model against the AR null.

[20] A half-life is the time taken for a given series to return to half of its initial value.

While all European currencies were quoted at long maturity (typically, sixty or ninety days), only core currencies were also quoted spot. To avoid corrections for the interest-rate component included in each long maturity,[21] we only collect data on currencies with an active spot exchange rates market. Between 1844 and 1870, there were only five such currencies: the pound sterling (London), the French franc (Paris), the mark Banco (Hamburg), the Dutch guilder (Amsterdam), and the South-German guilder (Frankfurt).[22]

Bill prices are collected from stock exchange bulletins (Amsterdam, Frankfurt, Paris) or their reprinting in the financial press (London, Hamburg). Among the twenty possible bilateral exchange rate relationships between our five financial centers, four series are missing as not all core currencies were quoted spot everywhere. This is illustrated in Figure 1. The most extreme cases are London on the one hand (whose currency was quoted spot everywhere else, but which only quoted spot two foreign currencies – viz. the French franc and the Dutch guilder) and Frankfurt on the other hand (which quoted spot all other currencies, but was only quoted spot in Paris).[23] Interestingly, Paris was the only place to both quote and be quoted by all other centers (more on this in Section 6.3).

Figure 1 about here

Gold and silver prices in each city were collected from the same sources as bill prices. Figure 2 summarizes the information on the available price quotes. It shows that market prices of both gold and silver ingots are available only in London, Paris and Hamburg, while Amsterdam and Frankfurt only quoted silver. We compute silver arbitrated pars for all available bilateral exchange relationships between our five centers. For the sake of robustness, we compute exchange rate deviations from both arbitrated pars (gold and silver) whenever gold was quoted on local financial market. To sum up, our database includes sixteen bilateral exchange rate relationships of which five can be checked against two different metallic benchmarks. This makes a total of twenty-one series of exchange rate deviations from an arbitrated metallic par.

Figure 2 about here

[21] The pricing of long exchange rate included the spot exchange rate and the offshore interest rate (De Roover, 1953) and there is no proper method to disentangle those dimensions.

[22] It is interesting to notice that before German unification, the Prussian thaler (i.e. Berlin's currency) was not quoted spot in any major international financial center.

[23] Seyd (1868, p. 443) explains the small number of foreign currencies quoted spot in London by the fact that the English banker "is under no necessity of seeking investment for his funds in Foreign securities of this kind", given the "so vast an amount of enterprise [that] continually extends the boundaries of commerce [in England]". By contrast, non-English bankers "do not so readily find convenient investment for large sums of money, and are therefore driven to deal in a variety of bills".

Following Officer (1996) and Canjels et al. (2004), we average bid and ask prices when both are available. We collect data at the weekly frequency to ensure consistency of our comparison of the threshold across the various pairs of markets. Actually, bills of exchanges were not quoted daily on all markets: for instance, Hamburg prices of sight bills are available only twice a week. Moreover, as Baillie and Bollerslev (2002) have shown, reducing the frequency (e.g. from daily to weekly) of exchange rate data decreases the time-dependent heteroscedasticity leading to inefficient estimates and suboptimal statistical inferences. Therefore, to avoid biasing the comparison, and because all markets quoted sight bills at least at the weekly frequency, we collect all available end-of-week prices. For some cities, no price is available for some sub-periods. As noted by Neal (1990), a missing price can indicates the inability to set a price, as was sometimes the case during period of financial tensions such as during the revolutions of 1848. This is the case with Frankfurt, for which our source was discontinued after June 23, 1866 perhaps in connection with its annexation by Prussia. Appendix Table 1 summarizes the main statistics for all series. The maximum number of weeks in the sample is equal to 1363 for the Hamburg-London pair. The minimum is 869 in the case of the London-Frankfurt pair. Except for bilateral exchanges rate with Frankfurt, most bilateral exchange series contain about 1,300 observations. Appendix Figure 1 plots the evolution of our variable x_t over the sample period.

5. Results

Equation (5) is estimated on stationary series of the exchange rate deviations. Using the NP and KPSS (when applicable) unit root tests, Table 2 shows that all series of the 1844-1870 period are stationary (there is no unit root in the series), which means that in the long-run, any deviation of the exchange rate of from the arbitrated par is followed by a return to parity.[24] Table 3 details the estimates of the threshold and of the half-life for the period 1844-1870. The unit of the thresholds is the percentage deviation from market parity and the unit of the half-life is in number of weeks.

Table 2 and Table 3 about here

In all series but two, the TAR threshold estimated is positive and significant, which points to the existence of some positive transaction cost before the deviation of the exchange rate returned to its mean. In two instances, the threshold is not significant, which points to the absence of any transaction cost before the deviation of the exchange rate started returning to its mean, once it deviated. Those two instances are the Amsterdam-on-Paris and Frankfurt-on-Hamburg pairs. Overall, the thresholds vary between a minimum 0.088% for Hamburg-on-Paris and a maximum 0.976% for Amsterdam-on-Hamburg. The half-lives for these two pairs are at three weeks and a half and one week and a half

[24] See Appendix Table 2 for the result of the stationarity tests.

respectively: this indicates that it took less than a month for the Hamburg-on-Paris exchange rate to return to half of its initial value when it deviated outside the band, but only a week and a half for the Amsterdam-on-Hamburg pair. The estimated threshold for the Paris-on-Amsterdam pair is equal to 0.677% and the half-life is two weeks and a half, while the one for Hamburg-on-London is at 0.666%. Interestingly, the estimated threshold for Paris-on-London (when parity is computed with gold) is at 0.427% and that the half-life is a week and a half. This has to be compared with Flandreau's (1996, p. 424) estimates of the direct cost of gold arbitrage, that are 0.985% before 1854 and 0.785% afterwards. A great connoisseur of the bullion markets of the time, Ernest Seyd, reported that in the late 1860s gold points were 0.5% around the metallic par for the Paris-on-London relationship (Seyd 1868, p. 394). For the London-on-Paris pair, Flandreau's (1996, p. 424) estimates are 0.575% before 1854 and 0.375% afterwards. This has to be compared to our 0.227% estimated threshold.[25]

Figure 3 about here

TAR-estimated threshold must be interpreted with care since their estimation rests on the assumption that the thresholds are constant during the whole period. We relax this assumption by estimating them by decades.[26] Figure 3 plots the thresholds and half-life of each of the twenty-one deviation series (i.e. sixteen market pairs, five of which double) during each of the three decades of the period (see Appendix Table 3 for details). The results suggest that thresholds varied noticeably across decades. For instance, while estimates for Hamburg-on-London were at 0.666% for the whole 1844-1870 period, we find a small 0.494% for 1844-1850, a mere 0.172% for 1851-1860, and a much higher 0.603% for 1861-1870. On the contrary, the Paris-on-Hamburg threshold for the deviation from the gold par levelled at higher levels than the estimated 0.149% for the whole 1844-1870 period, being 0.191% in 1844-1850, 0.257% in 1851-1860, and 0.207% in 1861-1870. The Paris-on-Hamburg thresholds for the deviation from the silver par are roughly comparable, with values of 0.374% in 1851-1860 and 0.161% in the 1861-1870. Figure 3 shows that the half-lives of the deviations, which levelled between two and three weeks, are comparable with the 2.8 weeks half-life estimated with data for the whole period.

When comparing the long-run threshold with the medium-run threshold, two points are noteworthy. First, all available direct evidence on gold points for this and for later periods (e.g. Seyd, 1868; Tate, 1868; Einzig, 1929; Morgenstern, 1959; Flandreau, 1996) suggest that our estimates are substantially smaller than one would expect. On this regard, our analysis systematically replicates the puzzle first raised by Canjels et al. (2004) – i.e., that TAR-computed thresholds are much lower than

[25] The discrepancy between Flandreau's (1996) silver points and our estimated threshold is similar, with silver point levelling at 0.625% for Paris-on-London and 0.475% for London-on-Paris (post-1854).

[26] We follow this partition criterion as it appears to us the most neutral one. We could have followed a different one (e.g. taking crises as cutting points, as in Nogues and Herranz, 2015), but our feeling is that such a choice might have generated biases in our results.

bullion points reconstructed from historical sources. In order to double-check whether the discrepancy between the two is an artefact of the choice of specific pairs, we replicates the exercise for as many different specifications as possible for the same pairs of cities – by looking at the opposite direction of arbitrage (e.g. by comparing the results for Paris-on-London with those for London-on-Paris) and by adopting a different metallic benchmark (e.g. by comparing the results for deviations from the gold arbitrated par with those for deviations from the silver arbitrated par). The estimates, reported in Appendix Table 3, do not reconcile the estimated thresholds with historically observed transaction costs. Our estimates are in fact much closer to the level of the financial transaction cost estimated for late-20th-century fiat-money regimes (see e.g. Coakley and Fuertes 2001). Given that the period was characterized by the absence of capital controls, this suggest that there was cheaper arbitrage available to traders than moving gold or silver across countries (more on this in Section 6.2).

Second, our estimations reveal serious discrepancies between the long-run and medium-run estimates of the threshold. One potential explanation may lie in the swings exhibited in the medium-run by the series. This may be linked to the qualitative properties of the exchange rate deviation for each decade, as reported in Table 2. It was not unusual that the threshold was non-significant when the series was stationary. For instance, both the Amsterdam-on-Hamburg and the Amsterdam-on-Paris pairs display an AR(1) process in the 1850s, which would point to an absence of transaction costs. Given that Amsterdam was heavily involved in the financing of the Hamburger or Parisian traders (Jonker, 1996), one might speculate that it was the high degree of competition on the Amsterdam bills market that had pushed the transaction costs to nil. Note that because the transaction cost of buying a bill is market-dependent, this is not necessarily symmetric. This pattern can also be found in the 1860s between London and Paris. When compared to today this pattern is not unusual, since the transaction costs associated with foreign exchange trading is also very low at present. Table 3 also reveals that it was not uncommon in the 1840s that the deviation from par of some market pairs was non-stationary. During the 1844-1850 period, the exchange rate deviations are non-stationary in five instances (Amsterdam-on-London, Amsterdam-on-Paris, London-on-Amsterdam, Hamburg-on-London, and Frankfurt-on-Paris). Despite the relative stability displayed by our exchange rate deviation series (see Appendix Figure 1), one must not lose sight with the fact that this was an epoch of dramatic shocks in Europe. A period of intense speculation linked to the Railway Mania (1844-1847) was followed first by huge financial and political shocks (1847-1849), then by a time of an unusual volatility of bullion prices following the Gold Rush (1849-1850). This suggests that the way data series are partitioned may have a very strong influence on econometric results, sometimes producing some outcomes (such as non-stationarity) that are completely at odds with the principle itself of re-equilibrating arbitrage.

To sum up, our analysis shows that transaction cost estimated through the TAR model are systematically smaller than actual gold or silver points reported by historical sources. Because our results are in line with those of the literature, this cannot be imputed to the quality of our computations or of our dataset. Moreover, we have also found that TAR-estimated thresholds are sensitive both to

the direction of the arbitrage and to the way time series are cut. Our evidence, therefore, points to the conclusion that TAR-computed thresholds cannot be interpreted as reflecting the transaction costs of bullion arbitrage: instead of the extra-gold-point mean-reverting pattern predicted by the classical gold-point arbitrage model, TAR estimates may actually happen to detect an *intra-gold-point* mean-reverting process. To put it differently, our analysis suggests that international arbitrage allowing for the re-equilibration of exchange rates in commodity-based monetary systems may have been of another nature than the bullion arbitrage envisaged by the classical model. The reasons why this may be the case are discussed in Section 6.

6. Discussion

6.1: The Limits to the Classical Gold-Point Arbitrage Model

As explained in Section 2.1, the classical gold-point arbitrage model rests on three fairly restrictive assumptions: 1) bilaterality, 2) non-substitutability of the arbitraged good, and 3) strict coincidence between bullion and currency flows. The three of them can actually be criticized.

Criticism of the most basic assumption of the classical gold-point arbitrage model – i.e., *bilaterality* – is put forward by Coleman (2007) When arbitrage between two locations is feasible at non-prohibitive costs through a third place – he argues – then *trilateral* arbitrage may occur even though the price margin does not exceed *bilateral* transaction costs. Focusing on the same historical example as Canjels et al. (2004), he shows that gold happened to be shipped from New York to London through Paris although the sterling/dollar exchange rate did not exceed the bilateral gold point. As such shipments prevented the exchange rate from reaching the bilateral gold point, the implication is that TAR-estimated thresholds will necessarily be lower than the actual bilateral cost of arbitraging gold or silver bullion. Coleman’s (2007) conclusion is very relevant. However, as trilateral bullion shipments tended to be quite cumbersome and costly, the number of occasions in which trilateral gold/silver arbitrage was cheaper than bilateral one must have been limited. On the whole, this explanation does not seem to be sufficient to account for the remarkable narrowness of TAR-estimated non-bullion-arbitrage bands.

A second source of criticality can be drawn from Flandreau (1996), who targets another important assumption of the classical gold-point arbitrage model – i.e., *non-substitutability* of the arbitraged good. When more than one kind of monetary assets is available to settle international payments – he argues – then arbitrage in *one* monetary instrument may occur even though the price margin does not exceed the transaction costs implied by arbitrage in *another* monetary instrument. Focusing on the London-Paris bilateral relationship in the same period as ours (when Britain was on gold and France

on bimetallism), he shows that silver shipments happened to occur between London and Paris although the sterling/franc exchange rate remained within the bilateral gold points (and vice-versa). As such shipments prevented the exchange rate from reaching the bilateral gold point, the implication is that TAR-estimated thresholds for gold are necessarily lower than the actual gold or silver points. No doubt, Flandreau's (1996) conclusion is very relevant. However, only five out of twenty-one bilateral exchange relationships in our sample actually had competing metallic instruments at the time. Moreover, this argument does not apply to the monometallic systems considered by the literature (Canjels et al., 2004; Esteves et al., 2007) – whose analysis leads, nonetheless, to the same results as ours.

A third source of criticality can be traced down to another crucial hypothesis of the classical gold-point arbitrage model – i.e., the *strict coincidence between bullion and currency flows*. This assumption is a very binding one: gold and money are thought to amount to the very same thing, and money/credit creation never occurs. This condition is fundamental from a theoretical viewpoint, as it ensures the applicability of threshold-regression analysis to exchange rate series: in fact, in case foreign currency could be created at will by the banking system (instead of being imported in the form of gold), there would be no reason for the exchange rate to display a mean-reverting behavior only after hitting the gold points. Unfortunately, the assumption of strict coincidence between bullion and currency flows seems to be way too restrictive to correspond to the actual workings of historical monetary systems (Esteves et al. 2007, p. 12). Foreign currency (in the form of drawing rights granted by foreign banks to local ones – which is what bills of exchange actually amounted to) could indeed be created without necessarily implying physical gold shipments. One important application of this critique comes from the extension of target-zone models to the classical gold standard (Bordo and MacDonald 2005; Flandreau and Komlos 2006). According to this literature, because the gold standard was a credible target zone, mean-reverting speculation systematically drove exchange rates back to the metallic par without any need for gold shipments to occur. This means that when the exchange rate rose, the banking system *did* create foreign currency and sold it against local one – at least, as long as it expected the price of local money to return to its real value (the metallic par). As such credit creation prevented the exchange rate from reaching the bilateral gold point, the implication is that TAR-estimated thresholds for gold will necessarily be lower than the actual gold or silver points. The conclusions of the target-zone literature are – again – very relevant. However, their direct applicability to our analysis is unclear. As we have computed our thresholds by using the exchange rate deviation from the *arbitrated* (and not from the *mint*) metallic par, our non-arbitrage bands are dynamic – and not static as in the classical gold-standard analysis. The metallic par was hence volatile, and in some cases it moved rather considerably (as e.g. for the London-Paris bilateral relationship, where the gold par varied as much as 5.82% between April 8, 1848 and February 1, 1851). This means that it might have been difficult for arbitrageurs to have converging expectations leading to mean-

reverting foreign exchange speculation. As such, even this explanation does not seem to be sufficient to account for our results.

6.2: An Alternative View: Cross-Exchange Arbitrage

While none of the three explanations examined in Section 6.1 can alone account for the puzzle we observed, any of them contains a crucial element of truth: three of the most basic assumptions of the classical gold-point arbitrage model (bilaterality, uniqueness of the payments instrument, impossibility of currency creation) may not hold in the context of historical monetary systems. Analyzing the theoretical implications of relaxing all of the three assumptions at the time is way beyond the scope of this paper, and we leave this task to future research. In what follows, we will bind ourselves to proposing a strategy for rationalizing our puzzle that is consistent with both historical evidence and the underlined limits of the gold-point arbitrage model. This strategy consists of focusing on the role played by *cross-exchange arbitrage*.

In the context of historical monetary systems, many options were available to an arbitrageur willing to settle a payment from location A to location B. First, he could buy foreign currency (bills of exchange on B) directly in A. Second, he could physically ship gold or silver directly from A to B. Third, he could – as suggested by Coleman (2007) – ship bullion to B through a third location C. But a fourth option was also available: he could buy foreign currency (bills of exchange on B) in a third location C. Cross-exchange arbitrage of this sort was very common in the 19th century, and archival sources from private banks abound with evidence of such practices (see e.g. Gille 1961-3). The existence of this form of arbitrage is, *per se*, proof of extensive violation of the three above-mentioned assumptions of the classical gold-point arbitrage model: 1) by definition, it was non-bilateral but trilateral; 2) it provided an additional, viable alternative to bullion shipments; and 3) it was based on payments instruments (bills of exchange) which could be created by the banking system without necessarily entailing bullion shipments.

We are not the first ones to underline the importance of cross-exchange arbitrage in the workings of commodity-based monetary systems. Morgenstern (1959) has been the first to take the exchange rate deviation from cross-exchange pars as an indicator of market integration under the classical gold standard. His intuition has been applied by Schubert (1989) to the 18th-century international monetary system. De Roover (1949) and then Li (2012) have provided extensive evidence of cross-exchange arbitrage already in the late-medieval and early-modern periods.

When this form of arbitrage is allowed to exist between two locations, it is possible to compute one cross-exchange par for any third location available as a trading partner. The cross-exchange par between A and B through C ($P_{C,t}^{par}$) will be equal to

$$P_{C,t}^{par} = \frac{P_{MC,t}^{A}}{P_{MC,t}^{C}} \cdot \frac{P_{MB,t}^{C}}{P_{MB,t}^{B}}$$

where $P_{MC,t}^{A}/P_{MC,t}^{C}$ is the direct exchange rate between A and C, and $P_{MB,t}^{C}/P_{MB,t}^{B}$ is the direct exchange rate between C and B. Following Morgenstern (1959), the direct exchange rate deviation from the cross-exchange par x_t^C, defined as

$$x_t^C = \frac{P_t^{A,B} - P_{C,t}^{par}}{P_{C,t}^{par}},$$

can then be taken as an indicator of financial integration. By comparing the deviations of the direct exchange rate from cross-exchange pars with its deviations from metallic pars (gold/silver mint and arbitrated pars), it is possible to have a sense of the role played by cross-exchange arbitrage in reducing the volatility of direct exchange rates. In case direct exchange rates are closer to cross-exchange pars than to metallic pars, it is possible to conclude that it was the activation of cross-exchange arbitrage (instead of bilateral bullion arbitrage) which kept exchange rates far from the actual bullion points.

6.3: Cross-Exchange Arbitrage: Evidence

In order to measure financial market integration along the lines proposed by Morgenstern (1959) and Schubert (1989), for each of our twenty-one bilateral pairs we compare the mean absolute deviation of the direct exchange rates from a number of benchmarks (mint pars, gold arbitrated pars, silver arbitrated pars, and cross-exchange pars through all third cities included in our sample).[27] Table 4 presents the results for every pair per decade. The table can be read as a sort of "horse race" among the different payments strategies (or "arbitrage routes") available to arbitrageurs, allowing to see which one is more likely to have exerted an influence on direct exchange rates by its proximity (and hence, by the activation of mean-reverting arbitrage of the kind). To provide a broader view, in

[27] As discussed in Section 4, information on spot exchange rates on all other four cities is not available in all five centers (that is why in Figure 1 we have sixteen links instead of twenty). This means that in some cases, the cross-exchange par cannot be computed properly. However, we do not think that lack of price information means lack of trading: after all, even though the price of sight bills of exchange was not officially quoted, the price of ninety-day bills was – meaning that trading was active between the two cities. As a result, to compute cross-exchange pars between A and B through C when the price in C of sight bills on B ($P_{MB,t}^{C}$) is unavailable, we substitute the missing rate $P_{MB,t}^{C}/P_{MB,t}^{B}$ with the inverse of the spot exchange rate on B in C ($P_{MC,t}^{C}/P_{MC,t}^{B}$). Deviations from cross-exchange rates computed in this way are given in italics in Table 4.

Appendix Table 4 we aggregate information from bilateral pairs in order to get general statistics for every "arbitrage route".[28] Aggregate values on mean absolute deviations are visualized in Figure 4.

Table 4 and Figure 4 about here

The results are unambiguous: in almost all cases, direct exchange rates used to be much closer to cross-exchange pars than to any bilateral metallic par. They always stayed furthest from mint pars, but also rather far from arbitrated pars – although a considerable improvement is recorded in the "performance" of gold arbitrated pars, probably reflecting broader utilization of this monetary metal after the Gold Rush of the early 1850s. By contrast, direct exchange rates tended to stay remarkably closer to cross-exchange pars. This seems to suggest that the mean-reverting processes detected by threshold-regression analysis had nothing to do with violations of the bullion points: in fact, the random walk of the exchange rate was constrained not by the occurrence of bilateral bullion arbitrage, but by the occurrence of cross-exchange arbitrage.[29] As cross-exchange arbitrage took place whenever the closest of the many available "cross-exchange points" were hit, the economic meaning of TAR-estimated thresholds is impossible to interpret in a clear-cut way.

Figure 4 also provides a number of insights on European financial integration in the mid-19th century. On the one hand, it suggests that information technology innovations played some role in fostering market integration: in stark contrast with Figure 3, Figure 4 points to a non-negligible improvement between the 1840s and the 1860s, as the average absolute deviation of direct spot exchange rates from basically all benchmarks declined throughout the period. On the other hand, our results confirm that there were hierarchies in the international monetary system. Direct exchange rates stayed systematically closer to some cross-exchange pars with respect to others: this suggests that because of unequal transaction costs, not all "cross-exchange arbitrage routes" were actually equally used by arbitrageurs. Figure 4 shows that the most active route for international adjustment consisted of cross-exchange arbitrage through Paris; in this particular ranking, London only came third after Amsterdam, while Hamburg supplied the less popular route.[30] While this conclusion may appear in

[28] Note that statistics in Appendix Table 4 are for all observations in the decade regardless of their belonging to the one or the other pair. This means that each observation contributes equally, but each pair contributes unequally to the computation of the aggregated value.

[29] Of course, there might be a possibility that the direct exchange rate deviation from cross-exchange pars is meaningless: transaction costs on cross-exchange arbitrage might have been prohibitive, so that the series happens to stay close to each other for purely fortuitous reasons. However, we think this to be very unlikely – at least, in the light of the above-mentioned historical evidence of extensive cross-exchange arbitrage (see Section 6.2). We think it much more likely that the direct exchange rate often hit the one or the other "cross-exchange point": whenever that occurred, cross-exchange arbitrage took place and prevented the direct exchange rate from moving further in the same direction.

[30] The case of Hamburg is special. As it is apparent in the Hamburg column in Table 4, cross-exchange pars through the Hanse town tend to be far from direct exchange rates when they are computed using Hamburg prices

contrast with received wisdom (traditionally considering London as the center of the international monetary system since the early 19th century), it is well consistent with the information provided by Figure 1 on the structure of the international payments network. Although London was a very important financial center, Paris appears to have provided international arbitrageurs with a more performing infrastructure for implementing international transactions in bills of exchange, as it was the only place to have the maximum number of currencies quoted there, but also the maximum number of markets quoting the French franc (see Figure1). One might speculate that this vantage situation had its roots in the peculiarities of France’s bimetallic standard.

7. Conclusions

With the aim of measuring the evolution of financial market integration in Europe at the time of the introduction of tremendous improvements in communication technologies (the telegraph and railways), we apply threshold-regression analysis to twenty-one series of weekly bilateral exchange rate deviation from an arbitrated metallic par between five core financial centers of the time. We find that TAR-computed estimates of transaction costs tend to be surprisingly small – in some cases, even nil – and sensitive to both the direction of arbitrage and the partitioning of the time series. We point out that there are good reasons why TAR-computed thresholds cannot be interpreted as transaction costs in the bullion trade (the gold points). In fact, the hypotheses underlying the classical gold-point arbitrage model appear to be too restrictive to correspond to the historical reality of commodity-based monetary systems. Building on a number of contributions, we suggest that multilateral currency arbitrage played a more crucial role than bilateral bullion arbitrage in capping exchange rate volatility. Looking at the deviation of the bilateral exchange rate from cross-exchange pars, we find that financial integration did actually increase substantially between 1844 and 1870. We conclude that the application of the TAR model to the estimates of gold or silver points of credible exchange rate is misleading. “Beneath the gold points” more complex arbitrage strategies were adopted by arbitrageurs thanks to the high sophistication of payments techniques at the time. Such strategies contributed much more substantially than “primitive” bullion arbitrage to the remarkable stability of the international monetary system.

(in roman), while they are much closer when they are computed using inverse exchange rate on Hamburg (in italics). This suggests that unobserved transaction costs (not included in official quotations) may have existed for accessing the Hamburg bill market, thus reducing its efficiency. These may have been tied to the restrictions in force at the local giro bank (Seyd 1868).

Data Sources

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Paris: *Cours général de la bourse de Paris publié par Jacques Bresson* (1844-1861); *Cours de la banque et de la bourse, anciens cours De Choisy et Bresson réunis* (1862-1870).
Hamburg: *Börsen-Halle: Hamburgische Abendzeitung für Handel, Schiffart und Politik* (1844-1860; 1862-1870); *Hamburger Geld- und Wechsel-Cours* (1860-1862).
Amsterdam: *Amsterdamsch Effectenblad* (1844-1870).
Frankfurt: *Börsen-Kursblatt von A. Sulzbach* (1844-1866).

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Figures and Tables

Figure 1: "In-degrees" (spot exchange rate on the given place quoted abroad) and "out-degrees" (spot exchange rate on a foreign place quoted in the given place) for Europe's five top financial centers, 1844-1870. Source: authors' database.

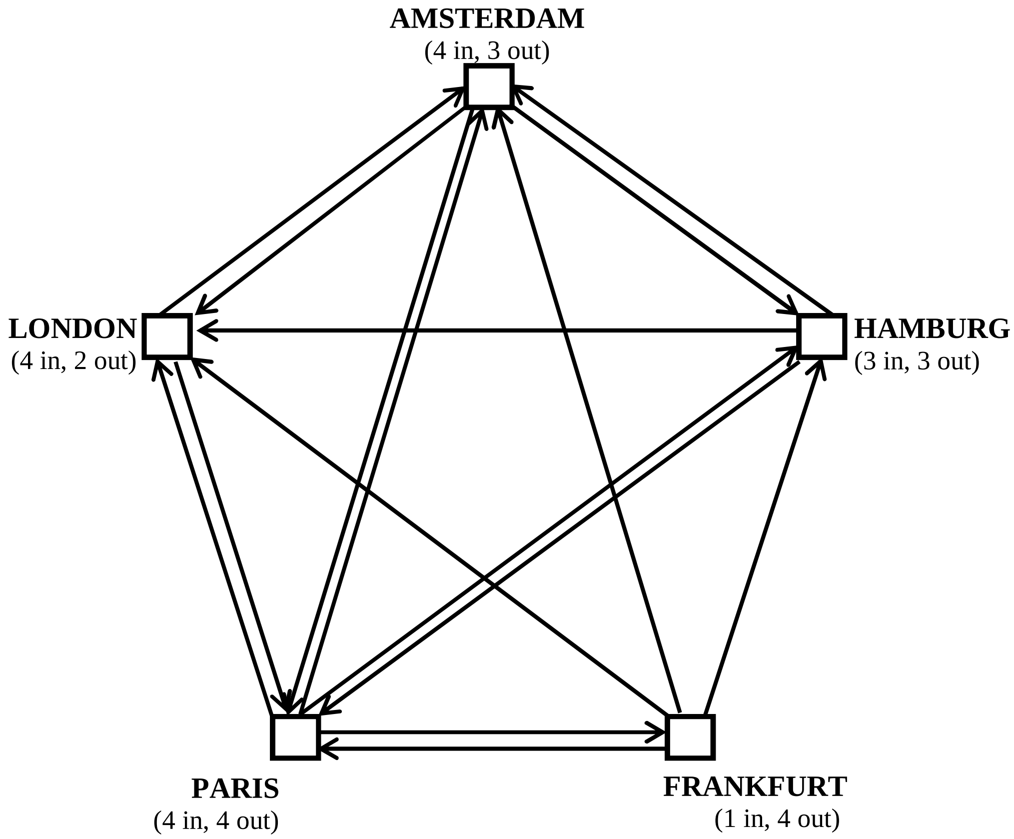


Figure 2: Metallic standards, bullion markets, and available metallic parities in the international monetary system, 1844-1870. Source: authors' database.
Note: G = gold (in black), S = silver (in grey).

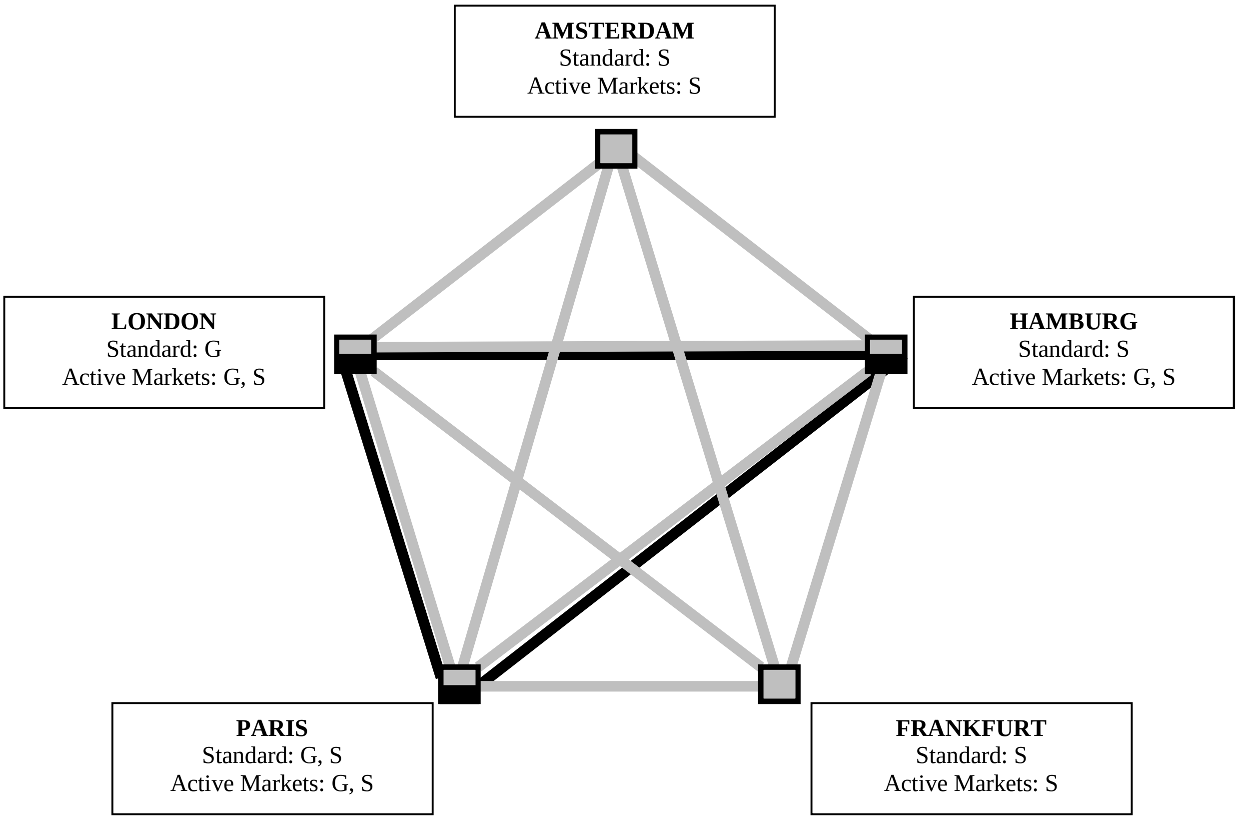
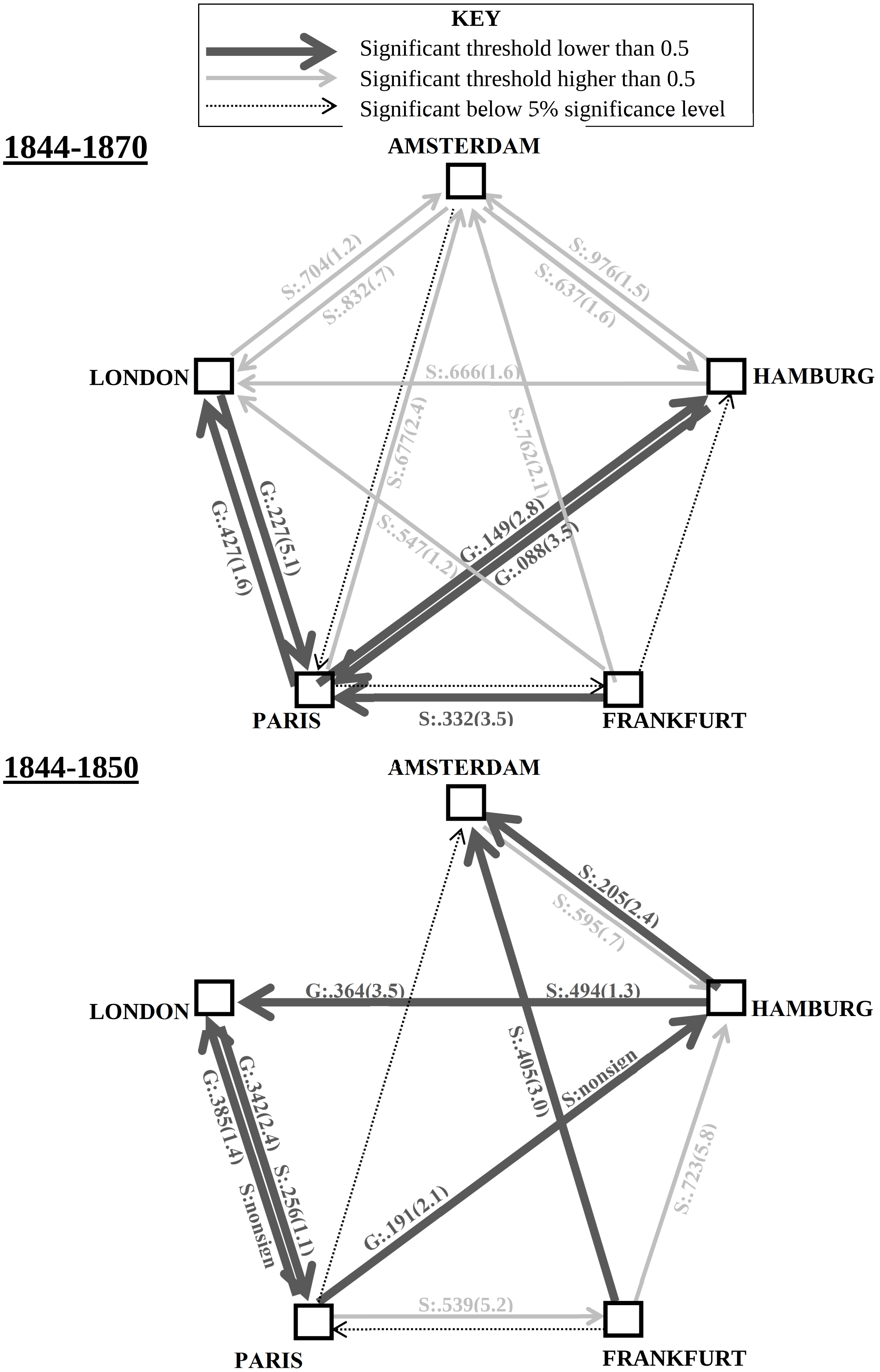
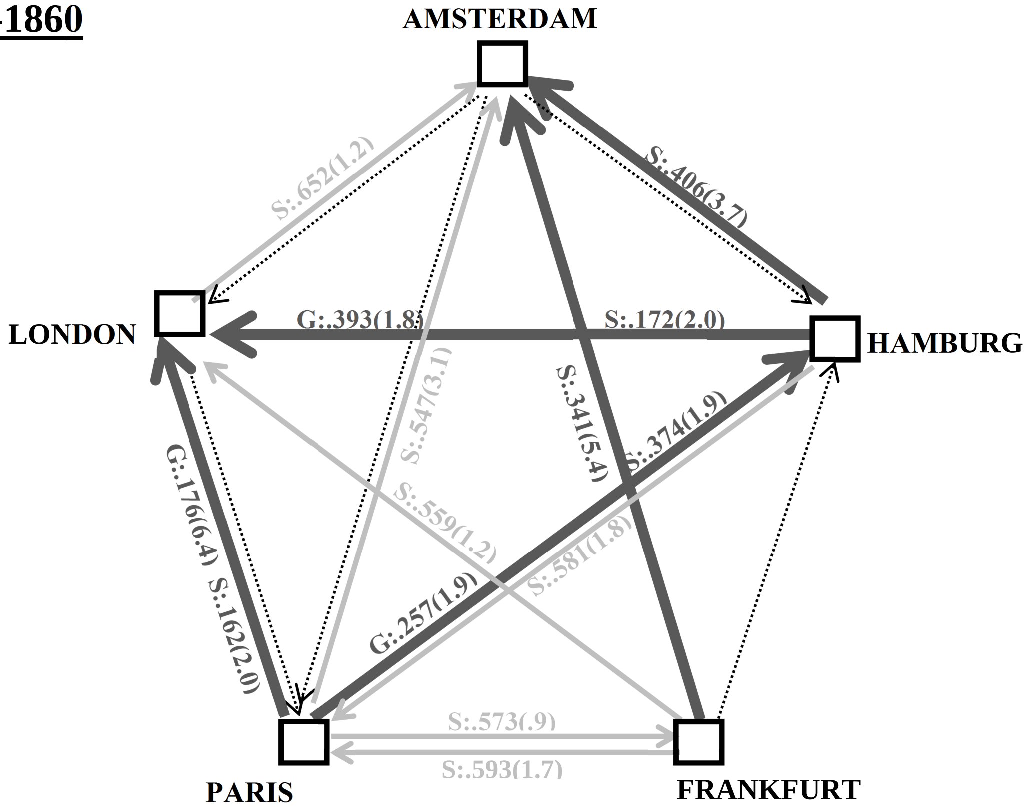


Figure 3: Estimation results of the threshold autoregressive model. Source: Appendix Table 4.

Note: Information provided close to each arrow includes 1) the benchmark metallic par (G = gold, S=silver); 2) the size of the estimated threshold; and 3) the half-life (in parentheses).



1851-1860



1861-1870

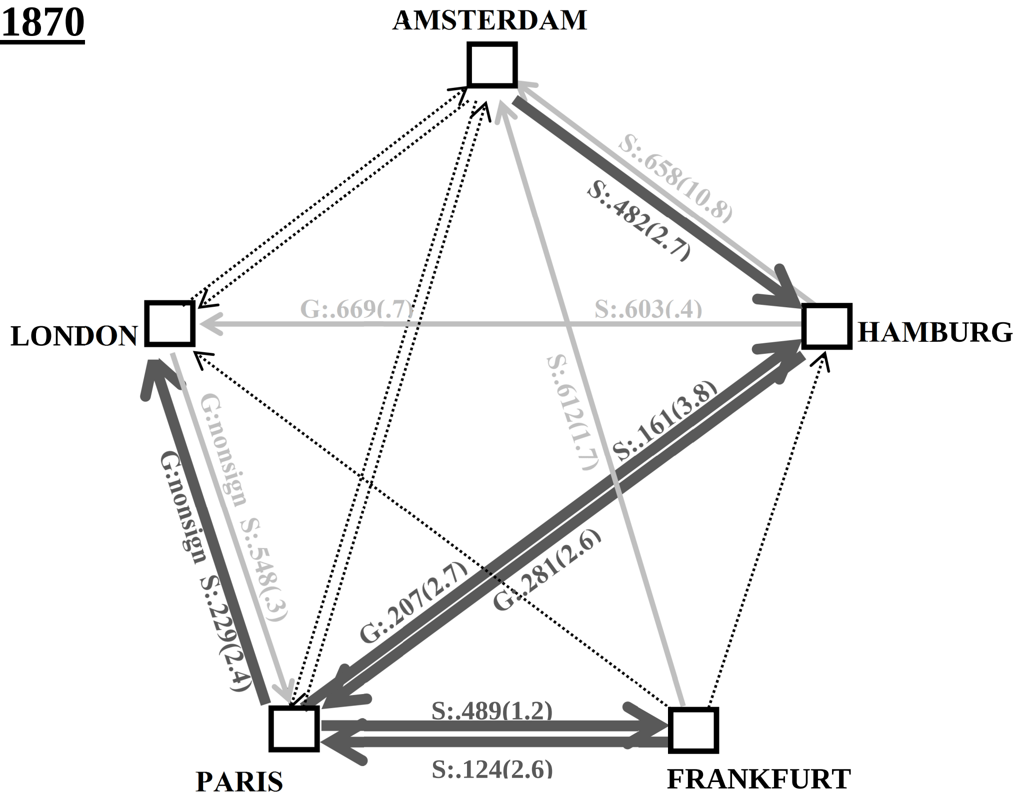


Figure 4: Mean absolute exchange rate deviation from a number of different benchmarks. Source: Appendix Table 4.

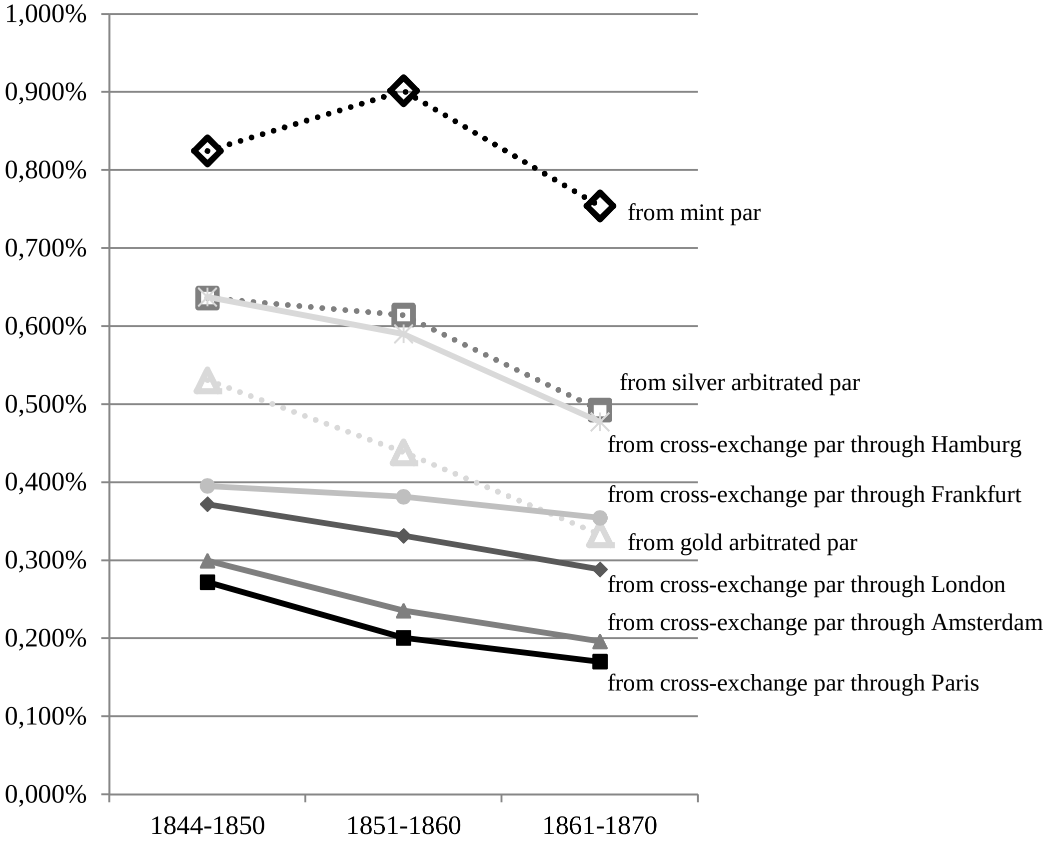


Table 1: Mint prices vs. market prices of bullions in five European cities

Metal	**Amsterdam** silver	**Frankfurt** silver	**Hamburg** silver	**London** gold	**Paris** gold	**Paris** silver
Mint price	105,8	105	118,67	136,57	3444,44	222,22
Market prices	104,59	104,49	118,69	136,35	3437,17	220,60
Average spread as % of Mint price	1,14%	0,49%	-0,0002%	0,16%	0,21%	0,33%
Median spread as % of Mint price	1,13%	0,40%	-0,0006%	0,16%	0,27%	0,35%
Standard Deviation	0,43%	0,40%	0,0010%	0,01%	0,20%	0,08%
Min spread as % Mint price	-0,90%	-0,25%	-0,0016%	0,00%	0,21%	0,33%
Max	4,06%	1,19%	0,0030%	0,16%	0,74%	0,39%

Notes: Mint prices and market price are the value in local currencies of 1 kilogram of metal and available at the weekly frequency. The spread is the difference between the Mint price and the local market price. The mint price did not change during the whole period of the study for any market.
Source: Authors' computation using data described in Section 4.

Table 2: Qualitative propriety of exchange rate deviation (results of the Ng-Perron/KPSS stationarity test and LLR linearity test). Source: Appendix Tables 2 and 3, Table 4.

		Market of destination				
	Market of origin	*Amsterdam*	*Frankfurt*	*Hamburg*	*London*	*Paris*
1844-1870	*Amsterdam*	-	NA	**TAR**	**TAR**	AR
	Frankfurt	**TAR**	-	AR	**TAR**	**TAR**
	Hamburg	**TAR**	NA	**-**	**TAR**	**TAR**
	London	**TAR**	NA	NA	-	**TAR**
	Paris	**TAR**	**TAR**	**TAR**	**TAR**	-
Sub-period 1 1844-1850	*Amsterdam*	-	NA	**TAR**	UR	UR
	Frankfurt	**TAR**	-	**TAR**	UR	AR
	Hamburg	**TAR**	NA	**-**	**TAR**	UR
	London	UR	NA	NA	-	**TAR**
	Paris	**TAR**	**TAR**	**TAR**	**TAR**	-
Sub-period 2 1851-1860	*Amsterdam*	-	NA	AR	**TAR**	AR
	Frankfurt	**TAR**	-	AR	**TAR**	**TAR**
	Hamburg	**TAR**	NA	-	**TAR**	UR
	London	**TAR**	NA	NA	-	AR
	Paris	**TAR**	**TAR**	**TAR**	**TAR**	-
Sub-period 3 1861-1870	*Amsterdam*	-	NA	**TAR**	AR	AR
	Frankfurt	**TAR**	-	AR	AR	**TAR**
	Hamburg	**TAR**	NA	-	**TAR**	**TAR**
	London	**TAR**	NA	NA	-	AR
	Paris	**TAR**	**TAR**	**TAR**	**TAR**	-

Note: NA = Data non available; AR = Autoregressive process; TAR = Threshold autoregressive process; UR = Unit root

Table 3: Estimation results of the threshold autoregressive model (1844-1870).
Source: authors' computations.

Market of origin	Market of destination	Metallic Par	parameters	estimate	t-stat.	C.I.	Half-life
Frankfurt	Hamburg	Silver	rho	-0.095	-4.252***	0.04	6.9
			threshold	0.081	1.247	0.13	
			Obs_out (Obs_in)	892(205)			
Frankfurt	Amsterdam	Silver	rho	-0.284	-4.200***	0.14	2.1
			threshold	0.762	8.221***	0.19	
			Obs_out (Obs_in)	170(918)			
Hamburg	London	Silver	rho	-0.345	-6.809***	0.10	1.6
			threshold	0.666	11.172***	0.12	
			Obs_out (Obs_in)	295(1058)			
Hamburg	Amsterdam	Silver	rho	-0.370	-5.068***	0.15	1.5
			threshold	0.976	11.058***	0.18	
			Obs_out (Obs_in)	208(1134)			
Amsterdam	Hamburg	Silver	rho	-0.357	-6.539***	0.11	1.6
			threshold	0.637	10.082***	0.13	
			Obs_out (Obs_in)	256(1086)			
Frankfurt	Paris	Silver	rho	-0.181	-4.552***	0.08	3.5
			threshold	0.332	4.874***	0.14	
			Obs_out (Obs_in)	482(462)			
London	Paris	Gold	rho	-0.127	-3.884***	0.07	5.1
			threshold	0.227	3.331***	0.14	
			Obs_out (Obs_in)	554(565)			
Paris	Amsterdam	Silver	rho	-0.254	-4.469***	0.11	2.4
			threshold	0.677	8.699***	0.16	
			Obs_out (Obs_in)	176(967)			
Paris	Frankfurt	Silver	rho	-0.097	-3.697***	0.05	6.8
			threshold	0.144	1.957*	0.15	
			Obs_out (Obs_in)	751(192)			
Paris	Hamburg	Gold	rho	-0.219	-7.352***	0.06	2.8
			threshold	0.149	2.847***	0.10	
			Obs_out (Obs_in)	911(373)			
Paris	London	Gold	rho	-0.346	-4.709***	0.15	1.6
			threshold	0.427	8.856***	0.10	
			Obs_out (Obs_in)	265(879)			
London	Amsterdam	Silver	rho	-0.437	-5.664***	0.15	1.2
			threshold	0.704	**10.018*** **	0.14	
			Obs_out (Obs_in)	256(745)			
Amsterdam	London	Silver	rho	-0.620	-5.805***	0.21	0.7
			threshold	0.832	11.381***	0.15	
			Obs_out (Obs_in)	154(847)			
Amsterdam	Paris	Silver	rho	-0.148	-5.329***	0.06	4.3
			threshold	0.114	**1.780**	0.13	
			Obs_out (Obs_in)	928(208)			
Frankfurt	London	Silver	rho	-0.429	-5.202***	0.16	1.2
			threshold	0.547	6.745***	0.16	
			Obs_out (Obs_in)	298(452)			
Hamburg	Paris	Gold	rho	-0.178	-10.349***	0.03	3.5
			threshold	0.088	**3.887*** **	0.05	
			Obs_out (Obs_in)	1102(195)			

Notes: ***, **, * denote the significance at the level of 1%, 5%, 10%, respectively. HL denotes the Half-Life in terms of weeks. Obs_out (Obs_in) denotes the number of observations outside (inside) the threshold. T-stat. is calculated based on the bootstrapped standard errors. C.I. denotes the confidence interval of the threshold estimate.

Table 4: Mean absolute exchange rate deviation from a number of different benchmarks, per bilateral pair. Source: authors' computations.

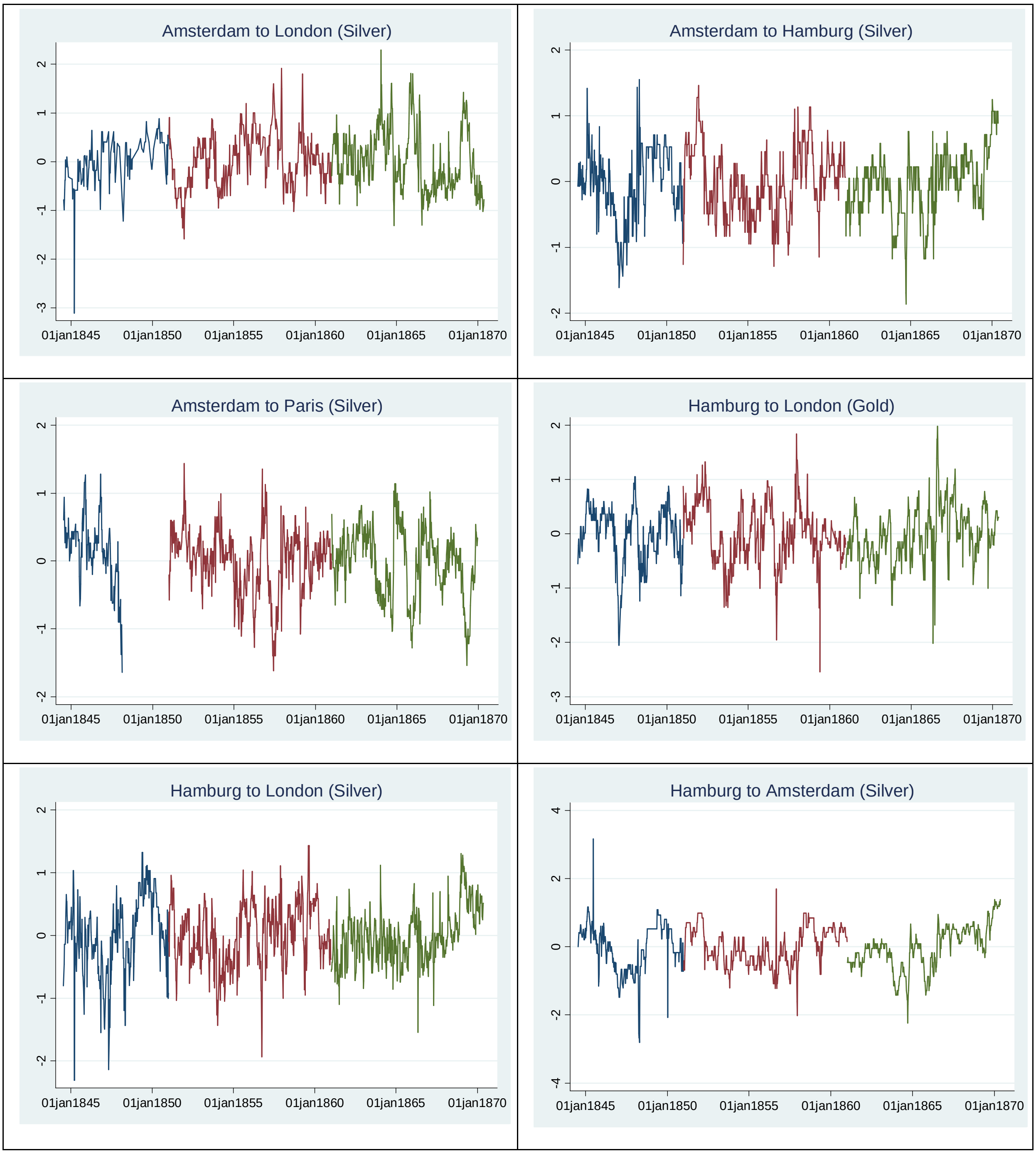
Origin	Destination	Period	from mint par	from silver arbitrated par	from gold arbitrated par	from CEP via London	from CEP via Paris	from CEP via Hamburg	from CEP via Amsterdam	from CEP via Frankfurt
Amsterdam	London	1844-50	NA	0.419%	NA	NA	0.264%	0.595%	NA	*0.202%*
		1851-60	NA	0.466%	NA	NA	0.182%	0.539%	NA	*0.183%*
		1861-70	NA	0.527%	NA	NA	0.160%	0.450%	NA	*0.194%*
Amsterdam	Hamburg	1844-50	1.026%	0.564%	NA	*0.595%*	0.290%	NA	NA	*0.247%*
		1851-60	0.768%	0.578%	NA	*0.539%*	0.301%	NA	NA	*0.241%*
		1861-70	1.084%	0.399%	NA	*0.450%*	0.229%	NA	NA	*0.192%*
Amsterdam	Paris	1844-50	0.669%	0.504%	NA	0.260%	NA	1.011%	NA	*0.288%*
		1851-60	1.613%	0.447%	NA	0.233%	NA	1.152%	NA	*0.321%*
		1861-70	1.231%	0.411%	NA	0.228%	NA	0.697%	NA	*0.265%*
Hamburg	London	1844-50	NA	1.284%	0.511%	NA	0.314%	NA	0.441%	*0.733%*
		1851-60	NA	0.816%	0.672%	NA	0.152%	NA	0.358%	*0.680%*
		1861-70	NA	0.559%	0.400%	NA	0.136%	NA	0.235%	*0.682%*
Hamburg	Amsterdam	1844-50	0.878%	1.476%	NA	0.357%	0.469%	NA	NA	*1.054%*
		1851-60	0.447%	1.341%	NA	0.228%	0.262%	NA	NA	*0.938%*
		1861-70	0.639%	0.800%	NA	0.161%	0.155%	NA	NA	*0.828%*
Hamburg	Paris	1844-50	0.722%	1.048%	0.660%	0.314%	NA	NA	0.538%	*0.640%*
		1851-60	1.413%	1.256%	0.490%	0.152%	NA	NA	0.643%	*0.809%*
		1861-70	0.967%	0.681%	0.390%	0.136%	NA	NA	0.539%	*0.811%*
Frankfurt	London	1844-50	NA	0.497%	NA	NA	0.231%	0.695%	0.202%	NA
		1851-60	NA	0.533%	NA	NA	0.161%	0.684%	0.183%	NA
		1861-70	NA	0.599%	NA	NA	0.160%	0.686%	0.193%	NA
Frankfurt	Hamburg	1844-50	0.565%	0.439%	NA	*0.702%*	0.206%	NA	0.247%	NA
		1851-60	0.500%	0.453%	NA	*0.689%*	0.198%	NA	0.241%	NA
		1861-70	0.397%	0.488%	NA	*0.691%*	0.203%	NA	0.192%	NA
Frankfurt	Amsterdam	1844-50	0.937%	0.425%	NA	0.224%	0.193%	1.040%	NA	NA
		1851-60	0.839%	0.441%	NA	0.194%	0.177%	0.928%	NA	NA
		1861-70	0.909%	0.465%	NA	0.197%	0.193%	0.821%	NA	NA
Frankfurt	Paris	1844-50	0.658%	0.520%	NA	0.211%	NA	0.558%	0.199%	NA
		1851-60	1.007%	0.459%	NA	0.164%	NA	0.630%	0.195%	NA
		1861-70	0.802%	0.369%	NA	0.148%	NA	0.635%	0.201%	NA
London	Amsterdam	1844-50	NA	0.426%	NA	NA	0.210%	*0.357%*	NA	*0.224%*
		1851-60	NA	0.552%	NA	NA	0.169%	*0.228%*	NA	*0.194%*
		1861-70	NA	0.528%	NA	NA	0.141%	*0.161%*	NA	*0.197%*
London	Paris	1844-50	1.285%	0.443%	0.518%	NA	NA	*0.313%*	0.293%	*0.211%*
		1851-60	0.482%	0.546%	0.317%	NA	NA	*0.153%*	0.213%	*0.164%*
		1861-70	0.201%	0.373%	0.161%	NA	NA	*0.140%*	0.196%	*0.149%*
Paris	Frankfurt	1844-50	0.653%	0.496%	NA	*0.245%*	NA	*0.270%*	*0.277%*	NA
		1851-60	0.909%	0.358%	NA	*0.274%*	NA	*0.267%*	*0.226%*	NA
		1861-70	0.660%	0.422%	NA	*0.206%*	NA	*0.199%*	*0.192%*	NA
Paris	London	1844-50	1.249%	0.442%	0.517%	NA	NA	0.562%	0.225%	0.231%
		1851-60	0.486%	0.526%	0.329%	NA	NA	0.661%	0.224%	0.161%

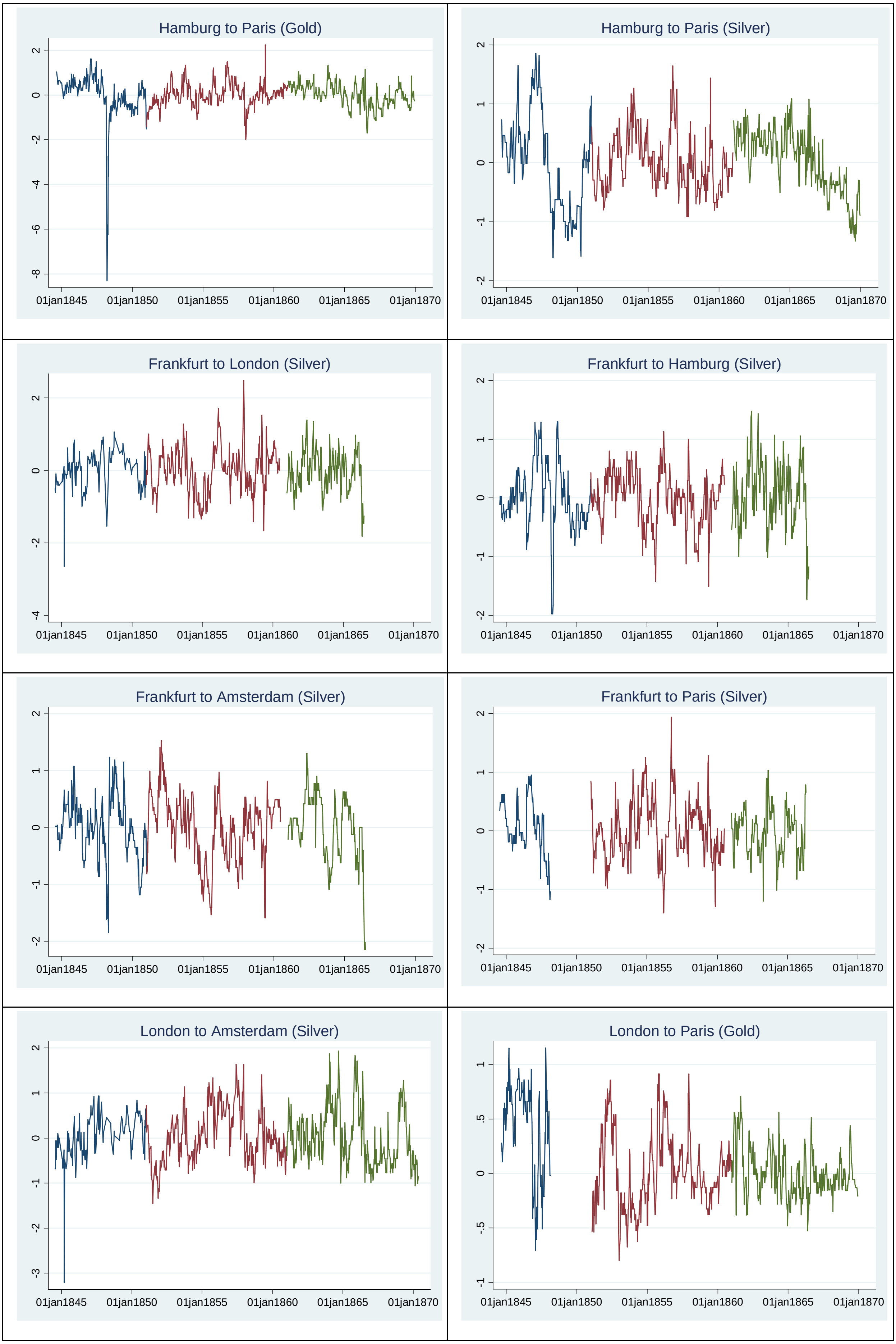
		1861-70	0.230%	0.381%	0.184%	NA	NA	0.523%	0.169%	0.160%
Paris	Hamburg	1844-50	0.624%	0.727%	0.445%	*0.566%*	NA	NA	0.279%	0.269%
		1851-60	0.824%	0.633%	0.388%	*0.667%*	NA	NA	0.238%	0.266%
		1861-70	0.651%	0.293%	0.534%	*0.527%*	NA	NA	0.186%	0.216%
Paris	Amsterdam	1844-50	0.606%	0.465%	NA	0.228%	NA	0.965%	NA	0.277%
		1851-60	1.512%	0.391%	NA	0.175%	NA	0.864%	NA	0.226%
		1861-70	1.169%	0.400%	NA	0.170%	NA	0.626%	NA	0.195%

Note: NA = Non applicable; CEP = Cross-Exchange Par. Values in italics denote that the cross-exchange par has been computed through using a proxy for unavailable direct spot exchange rate series (see text).

Appendix Figures and Tables

Appendix Figure 1: Exchange rate deviations (centered, as percent of the metallic market par). Source: authors' database.

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Hamburg to Paris (Silver)
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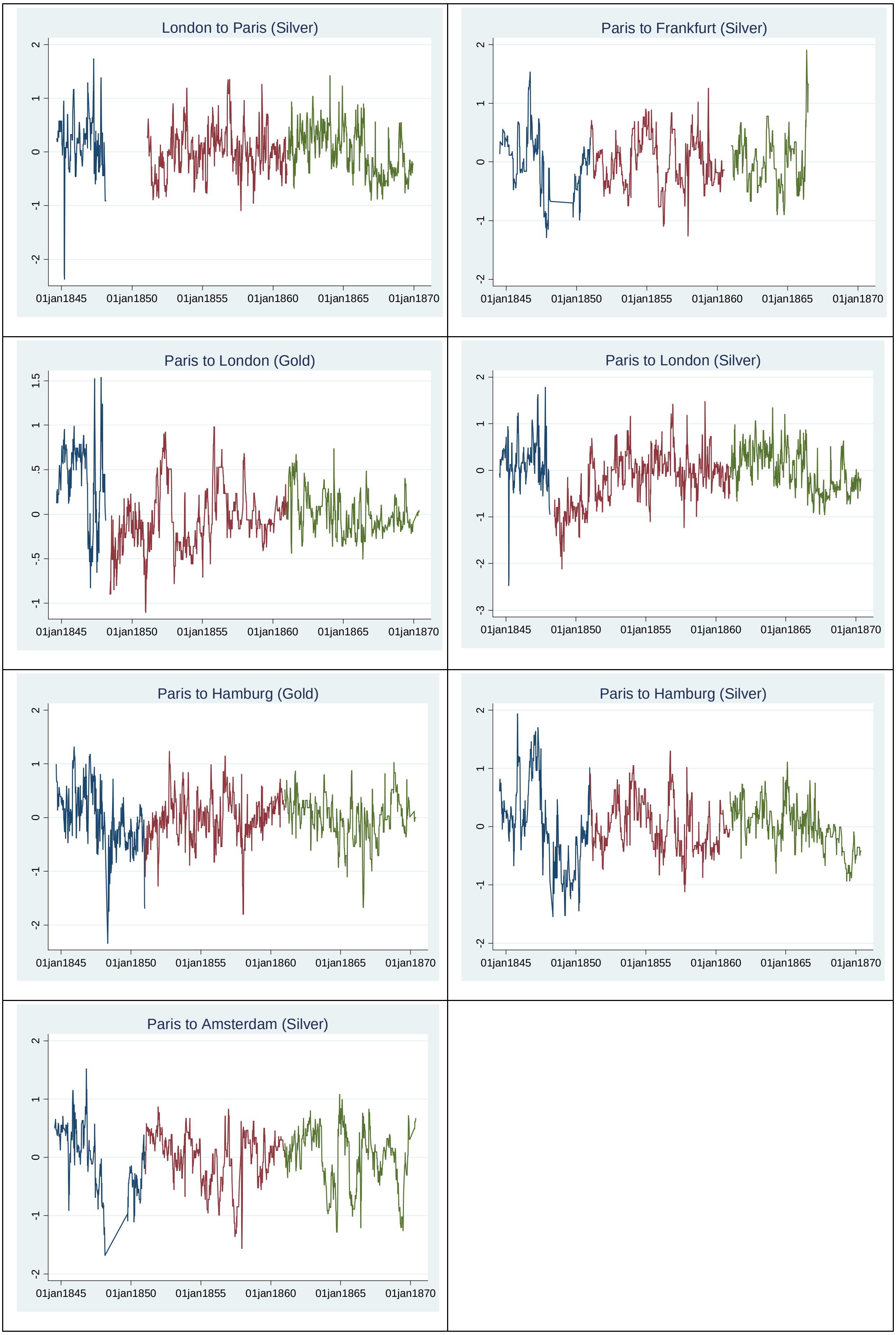
London to Paris (Silver)
Paris to Frankfurt (Silver)
Paris to London (Gold)
Paris to London (Silver)
Paris to Hamburg (Gold)
Paris to Hamburg (Silver)
Paris to Amsterdam (Silver)
01jan1845
01jan1850
01jan1855
01jan1860
01jan1865
01jan1870

Appendix Table 1: Descriptive statistics of exchange rate deviation from pars (percentage, 1844-70).
Source: authors' computations.

Exchange rate deviations							
Market of origin	Market of destination	Metallic Par	**Obs.**	**Mean**	**Std. Dev.**	**Min.**	**Max.**
Amsterdam	London	Silver	1062	.0352486	.5943434	-3.420028	2.326309
Amsterdam	Hamburg	Silver	1343	-.3224032	.5395484	-2.053945	1.154303
Amsterdam	Paris	Silver	1236	.1600432	.5132257	-1.531136	1.6951
Hamburg	London	Gold	1354	-.3541669	.5775922	-3.132201	1.933399
Hamburg	London	Silver	1363	-.7923461	.5800259	-3.573215	.8237265
Hamburg	Amsterdam	Silver	1345	-1.110908	.7021279	-4.232888	1.741993
Hamburg	Paris	Gold	1322	.2357863	.6652008	-8.017892	2.624112
Hamburg	Paris	Silver	1363	.9608324	.6673753	-.7311863	2.919179
Frankfurt	London	Silver	819	.1695474	.6491225	-3.075492	2.682827
Frankfurt	Hamburg	Silver	1106	.3034676	.4725659	-1.902453	1.506885
Frankfurt	Amsterdam	Silver	1097	-.0812614	.5661545	-2.045034	1.415939
Frankfurt	Paris	Silver	1019	.25589	.5343912	-1.288267	4.023231
London	Amsterdam	Silver	1053	.2210432	.6179678	-3.420028	2.173582
London	Paris	Gold	1334	.2184277	.5402375	-2.512836	3.261094
London	Paris	Silver	1287	-.0783297	.4460277	-5.87165	1.060725
Paris	Frankfurt	Silver	1018	.0863187	.5124626	-1.193255	1.893739
Paris	London	Gold	1317	-.1182072	.4399637	-5.807687	1.421984
Paris	London	Silver	1359	.1699738	.5443407	-2.653526	3.521391
Paris	Hamburg	Gold	1300	-.3219821	.4669243	-2.479944	1.172605
Paris	Hamburg	Silver	1337	.3886825	.5687226	-1.009306	2.475056
Paris	Amsterdam	Silver	1225	.0767947	.4918173	-1.504622	1.695973

Appendix Table 2: Ng-Perron/KPSS unit root test for exchange rate deviations from arbitrated pars. Source: authors' computations.

Exchange rate deviation			**1844-1850**				**1851-1860**				**1861-1870**			
Market of origin	**Market of destination**	**Metallic Par**	**MZa**	**MZt**	**Lag**	**Obs.**	**MZa**	**MZt**	**Lag**	**Obs.**	**MZa**	**MZt**	**Lag**	**Obs.**
Amsterdam	London	Silver	1.718766***k			158	-16.03790***	-2.762890***	1	324	-13.49110**	-2.568660**	7	486
Amsterdam	Hamburg	Silver	-28.96670***	-3.725160***	1	298	0.334788*k			522	-25.6380***	-3.44646***	2	503
Amsterdam	Paris	Silver	-13.96040t	-2.345410t	1	160	-22.54190***	-3.352410***	7	510	-11.03770**	-2.343210**	2	455
Hamburg	London	Gold	-8.801280 **	-2.079640**	3	332	-8.821320**	-2.040980**	3	511	-14.68350***	-2.514370**	8	507
Hamburg	London	Silver	-7.893620*	-1.983640**	4	332	-28.73520***	-3.778310***	10	520	-16.31150*	-2.844430*	14	509
Hamburg	Amsterdam	Silver	-19.22610***	-3.050100 ***	2	300	-12.18730**	-2.426800**	2	520	-8.551340**	-1.862180*	0	507
Hamburg	Paris	Gold	-7.126130t	-1.724690t	3	321	-4.570840	-1.398520	2	511	-14.67780***	-2.655060***	4	453
Hamburg	Paris	Silver	-5.020050	-1.568260	0	327	-16.77720***	-2.884210***	1	520	-3.937470	-1.152950	4	467
Frankfurt	London	Silver	0.480023**k			104	-21.30410***	-3.256300***	1	496	-22.77610***	-3.373410***	0	261
Frankfurt	Hamburg	Silver	-18.05540 ***	-2.982480***	0	330	-21.73560***	-3.294120***	2	496	-23.46390***	-3.276200***	0	268
Frankfurt	Amsterdam	Silver	-26.22950***	-3.563410 ***	2	307	-10.83150**	-2.287020**	2	496	-11.79840**	-2.418700**	1	272
Frankfurt	Paris	Silver	-6.568620*	-1.452820	0	188	-10.16370**	-2.219380**	2	478	-19.94310***	-3.132320***	2	268
London	Amsterdam	Silver	1.614241 ***k			149	-23.47070***	-3.368190***	0	321	-15.3799***	-2.71793***	7	490
London	Paris	Gold	-50.04240***	-4.901890***	2	156	-22.69440***	-3.296740***	6	502	-20.14190***	-3.161110***	8	463
London	Paris	Silver	-13.21590**	-2.539270**	0	156	-9.516030**	-2.139730**	0	480	-48.35910***	-4.908690***	0	451
Paris	Frankfurt	Silver	-12.57070**	-2.411890 **	0	188	-11.98470**	-2.407100**	4	476	-20.62930***	-3.188290***	0	268
Paris	London	Gold	-12.4014**	-2.47705**	2	183	-9.466020**	-2.146160**	0	496	-53.26690***	-5.159020***	0	455
Paris	London	Silver	-31.46060***	-3.841360***	8	183	-30.45440***	-3.825520***	6	518	-16.23460***	-2.843600***	8	461
Paris	Hamburg	Gold	-20.51890**t	-3.035090 **t	3	337	-13.26490**	-2.516280**	0	502	-10.94480**	-2.312470**	7	453
Paris	Hamburg	Silver	-11.55640**	-2.397350**	0	321	-5.613990	-1.613350	4	511	-5.751710*	-1.488580	5	461
Paris	Amsterdam	Silver	-21.15810**t	-2.921920 **t	0	160	-22.91210***	-3.381350***	5	505	-22.4079***	-3.34599***	0	455

Notes: Only constant is included; t indicates the inclusion of linear trend and constant (following Canjels et al., 2004, we introduce a linear trend as well to see if the process is trend-stationary); the optimal number of lags is chosen by minimizing the Modified SIC; ***, *, * are Significance at 1, 5, and 10 percent, respectively for rejecting the unit root null hypothesis. MZa and MZt denote efficient versions of the PP tests based on GLS detrending procedure (Ng and Perron, 2001, table 1). k means that the KPSS test (Kwiatkowski et al., 1992), which has a stationary null, is applied and that the LM test statistics are reported.

Appendix Table 3: Estimation results of the threshold autoregressive model for the three sub-periods. Source: authors' computations.

Market of origin	Market of destination	Metallic Par	parameters	estimate	t-stat.	C.I.	HL	estimate	t-stat.	C.I.	HL	estimate	t-stat.	C.I.	HL
				1844-1850				**1851-1860**				**1861-1870**			
Amsterdam	London	Silver	rho	**UR**				-0.244	-4.000***	0.12	2.5	-0.166	-3.074***	0.11	3.8
			threshold					0.167	1.942*	0.17		0.178	1.369	0.26	
			Obs_out (Obs_in)					304(102)				421(75)			
Amsterdam	Paris	Silver	rho	**UR**				-0.186	-3.694***	0.1	3.4	-0.142	-2.512**	0.11	4.5
			threshold					0.095	1.302	0.15		0.148	1.446	0.2	
			Obs_out (Obs_in)					425(87)				342(118)			
Amsterdam	Hamburg	Silver	rho	-0.638	-4.246***	0.30	0.7	-0.161	-2.890***	0.11	4.0	-0.230	-3.793***	0.12	2.7
			threshold	0.595	7.237***	0.16		0.106	1.190	0.18		0.482	4.745***	0.2	
			Obs_out (Obs_in)	53(261)				415(106)				126(379)			
Hamburg	London	Gold	rho	-0.180	-2.022**	0.18	3.5	-0.325	-4.221***	0.15	1.8	-0.655	-5.157***	0.25	0.7
			threshold	0.364	2.737***	0.27		0.393	4.367***	0.18		0.669	10.967***	0.12	
			Obs_out (Obs_in)	137(195)				259(253)				77(430)			
Hamburg	London	Silver	rho	-0.404	-3.848***	0.21	1.3	-0.293	-4.726***	0.12	2.0	-0.86	-5.119***	0.34	0.4
			threshold	0.494	5.200****	0.19		0.172	2.389**	0.14		0.603	8.868***	0.14	
			Obs_out (Obs_in)	125(207)				402(118)				86(422)			
Hamburg	Amsterdam	Silver	rho	-0.252	-3.452***	0.15	2.4	-0.171	-3.420***	0.1	3.7	-0.062	-1.127	0.11	10.8
			threshold	0.205	1.990**	0.21		0.406	3.593***	0.23		0.658	2.730***	0.48	
			Obs_out (Obs_in)	245(70)				289(229)				126(381)			
Hamburg	Paris	Gold	rho	**UR**				**UR**				-0.236	-3.836***	0.12	2.6
			threshold									0.281	4.213***	0.13	
			Obs_out (Obs_in)									244(215)			
Hamburg	Paris	Silver	rho	**UR**				-0.325	-3.099***	0.21	1.8	UR			
			threshold					0.581	5.414***	0.21					
			Obs_out (Obs_in)					110(410)							
Frankfurt	London	Silver	rho	**UR**				-0.435	-3.718***	0.23	1.2	-0.259	-3.548***	0.15	2.3
			threshold					0.559	4.545***	0.25		0.101	1.312	0.15	
			Obs_out (Obs_in)					139(238)				227(41)			
Frankfurt	Hamburg	Silver	rho	-0.113	-1.413	0.16	5.8	-0.130	-2.600**	0.1	5.0	-0.116	-1.105	0.21	5.6
			threshold	0.723	3.286***	0.44		0.084	0.923	0.18		0.066	0.702	0.19	
			Obs_out (Obs_in)	53(278)				389(103)				228(44)			
Frankfurt	Amsterdam	Silver	rho	-0.209	-2.297**	0.18	3.0	-0.121	-2.017**	0.12	5.4	-0.335	-2.577***	0.26	1.7
			threshold	0.405	3.894***	0.21		0.341	2.258**	0.3		0.612	5.368***	0.23	
			Obs_out (Obs_in)	113(207)				268(224)				58(216)			
Frankfurt	Paris	Silver	rho	-0.064	-0.548	0.23	10.6	-0.340	-3.247***	0.21	1.7	-0.233	-3.721***	0.13	2.6
			threshold	0.200	1.018	0.39		0.593	5.682***	0.21		0.124	2.077**	0.12	
			Obs_out (Obs_in)	122(65)				106(377)				219(53)			
London	Amsterdam	Silver	rho	**UR**				-0.442	-3.168***	0.28	1.2	-0.148	-2.631**	0.11	4.3
			threshold					0.652	4.902***	0.27		0.248	2.040*	0.24	
			Obs_out (Obs_in)					105(299)				391(107)			
London	Paris	Silver	rho	-0.457	-5.455***	0.17	1.1	-0.238	-5.026	0.09	2.5	-0.927	-5.429	0.34	0.3
			threshold	0.256	3.910***	0.13		0.077	1.548	0.10		0.548	9.187***	0.12	

			Obs_out (Obs_in)	179(135)				411(102)				99(405)			
London	Paris	Gold	rho	-0.248	-1.814	0.27	2.4	-0.093	-1.719	0.11	7.1	-0.157	-2.280**	0.14	4.1
			threshold	0.342	2.579***	0.26		0.084	1.108	0.15		0.059	1.141	0.10	
			Obs_out (Obs_in)	72(95)				401(91)				339(119)			
Paris	Frankfurt	Silver	rho	-0.124	-0.816	0.3	5.2	-0.549	-3.866***	0.28	0.9	-0.452	-2.598***	0.35	1.2
			threshold	0.539	2.274**	0.47		0.573	7.253***	0.16		0.489	4.990***	0.2	
			Obs_out (Obs_in)	48(139)				74(408)				46(226)			
Paris	London	Gold	rho	-0.389	-2.037**	0.38	1.4	-0.102	-1.619	0.13	6.4	-0.165	-2.619***	0.13	3.8
			threshold	0.385	4.010***	0.19		0.176	1.978**	0.18		0.063	1.537	0.08	
			Obs_out (Obs_in)	58 (124)				276(224)				364(96)			
		Silver	rho	-0.418	-4.309***	0.19	1.3	-0.299	-5.537***	0.11	2	-0.253	-3.514***	0.14	2.4
			threshold	0.124	1.57	0.16		0.162	2.893***	0.11		0.229	2.759***	0.17	
			Obs_out (Obs_in)	134(48)				289(228)				331(132)			
Paris	Hamburg	Gold	rho	-0.284	-3.595***	0.16	2.1	-0.31	-4.697***	0.13	1.9	-0.229	-4.018***	0.11	2.7
			threshold	0.191	2.011**	0.19		0.257	3.894***	0.13		0.207	3.339***	0.12	
			Obs_out (Obs_in)	228(88)				246(261)				253(206)			
		Silver	rho	-0.083	-1.277	0.13	8	-0.302	-3.432***	0.18	1.9	-0.167	-3.212***	0.1	3.8
			threshold	0.194	1.016	0.38		0.374	4.110***	0.18		0.161	2.403***	0.13	
			Obs_out (Obs_in)	236(85)				212(302)				289(174)			
Paris	Amsterdam	Silver	rho	-0.101	-0.828	0.24	6.5	-0.198	-2.712***	0.15	3.1	-0.099	-1.800*	0.11	6.6
			threshold	0.084	0.414	0.41		0.547	5.160***	0.21		0.229	1.941*	0.24	
			Obs_out (Obs_in)	141(31)				81(428)				286(174)			

Notes: ***, **, * denote the significance at the level of 1%, 5%, 10%, respectively. NS denotes that the data are non-stationary for the relevant period. HL denotes the Half-Life in terms of weeks. Obs_out (Obs_in) denotes the number of observations outside (inside) the threshold. T-stat. is calculated based on the bootstrapped standard errors. C.I. denotes the confidence interval of the threshold estimate.

Appendix Table 4: Descriptive statistics of absolute exchange rate deviations from a number of different benchmarks, per decade. Source: authors' computations.

		from mint par	from silver arbitrated par	from gold arbitrated par	from CEP via London	from CEP via Paris	from CEP via Hamburg	from CEP via Amsterdam	from CEP via Frankfurt
1844-1850	Mean	0.824%	0.636%	0.531%	0.372%	0.272%	0.637%	0.299%	0.395%
	Median	0.716%	0.473%	0.440%	0.273%	0.190%	0.555%	0.222%	0.263%
	Standard Deviation	0.617%	0.570%	0.557%	0.382%	0.351%	0.500%	0.304%	0.424%
	Number of Observations	3993	5315	1663	3253	2618	3270	2963	3603
1851-1860	Mean	0.902%	0.614%	0.438%	0.331%	0.201%	0.590%	0.235%	0.381%
	Median	0.780%	0.502%	0.354%	0.238%	0.158%	0.568%	0.185%	0.250%
	Standard Deviation	0.648%	0.477%	0.353%	0.298%	0.179%	0.397%	0.207%	0.359%
	Number of Observations	6167	8221	2592	5078	4066	5060	4045	5407
1861-1870	Mean	0.754%	0.492%	0.333%	0.288%	0.170%	0.477%	0.196%	0.354%
	Median	0.636%	0.414%	0.243%	0.199%	0.129%	0.417%	0.154%	0.230%
	Standard Deviation	0.565%	0.384%	0.307%	0.278%	0.172%	0.356%	0.173%	0.336%
	Number of Observations	5167	6456	2523	4206	3404	4207	3201	3371

Note: CEP = Cross-Exchange Par. Statistics are for all appropriate observations in the decade (see text).