Estimating Financial Integration in the Middle Ages: What Can We Learn from a TAR Model?

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We estimate a threshold autoregressive model to assess medieval financial integration. Our approach is based on the analysis of deviations between exchange rates and parity, which in a fully integrated market should not exceed bullion points. Hence, the time needed for adjustment, following a violation of the bullion points, is a measure of integration. We apply this approach to exchange between fourteenth- and fifteenth-century Flanders, Lübeck, and Prussia, results showing that whereas it took about eight months to reduce deviations between Flanders and Lübeck by 50 percent, those between Flanders and Prussia were roughly twice as persistent.

Market integration in preindustrial Europe is a subject that is receiving increasing attention. Most recent studies concern markets for commodities such as grain or spices and make use of the method based on the Law of One Price.[1] In this article, we suggest approaching the subject from a different direction, using new data and a different and new method.

Our focus is on financial markets, which are a suitable benchmark for other commodities. Financial markets integrated more easily than any others, so that it seems obvious that when they were badly integrated, markets for other commodities fared even worse. Our method for analysing their integration is simple enough. In a world with commodity money and perfect monetary integration, exchange rates are pinned down by the bullion content of coins; in the case we are analyzing here, by their content of silver. In the presence of transaction and transport costs, exchange rates can fluctuate randomly around silver parity up to these costs, which in effect define silver points.[2] Because we can ob-

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[1] Compare Persson, *Grain Markets*.

[2] Officer, *Between the Dollar-Sterling Gold Points*; Sergent and Velde, *Big Problem*; and Canjels, Prakash-Canjels, and Taylor, "Measuring Market Integration."

serve both the silver content of coins and the nominal exchange rates at which they were traded, we can estimate the silver points on the one hand, and the time it took to adjust following their violation on the other.[3] Hence, to assess the degree of financial integration between regions, we use both the estimated silver points and the time it took for adjustment: the farther apart the silver points were, and the longer adjustment took, the less well-integrated was the market.

We chose to study the region that was dominated by the Hanseatic League in the fourteenth and fifteenth centuries. The period is particularly suitable because, at that time, fiat money still played a minor role. Bills of exhange were used but, before they became negotiable in the late sixteenth and seventeenth centuries, prices that were independent from the exchange rates of coins could hardly develop for them.[4] On the whole, the late Middle Ages was still an age of hard money.[5]

As for the region, the main reason why we chose it was that we were able to collect a broad, new data set based on relatively homogeneous sources such as the account books of merchants and urban councils. Also, the Hanseatic area is easy to analyze because, in contrast to most of Western Europe, it was dominated by currencies based on only one precious metal, i.e., silver.[6] In bimetallic systems such as that existing at the time in England, determining deviations from parity requires considering changes in the relative prices of silver and gold. The relevant data are not only difficult to come by, but also complicated to interpret, due to the frequency of political interventions into the money market where the exchange of gold for silver was concerned.[7] Where only one kind of specie was used, we can neglect its price as expressed in the other kind of precious metal, and political manipulations of exchange rates were much rarer. Finally, the Hanseatic area has the advantage of linking a highly developed region, i.e., the Netherlands, with the Baltic, which was a rather backward zone.[8] This makes it likely that our find-

[3] Canjels, Prakash-Canjels, and Taylor ("Measuring Market Integration") are following a related approach with regard to the late nineteenth- and early-twentieth-century gold standard period.

[4] We are well aware of the possibility that rates quoted in bills of exchange may have contained a hidden interest rate (see de Roover, *Bruges Money Market* pp. 32 ff.), and that this might distort our data. However, as almost all quotations that we found in bills of exchange are from the first two decades of the fifteenth century, and as we have very few other observations from that period, there is insufficient material to determine how far exchange rates of both types diverged. The full data that we used are given in Volckart and Wolf, "Estimating Medieval Market Integration" (accessible at http://www.wiwi.hu-berlin.de/wg/volckart/14_16_exchange_ rates.xls). There, we indicate the type of quotation, using the categories developed by Spufford, *Handbook*, pp. l ff.

[5] Spufford, *Handbook*, p. xxxi; and Day, "Great Bullion Famine," p. 2.

[6] Spufford, *Money*, pp. 282 f.

[7] Compare Munro, *Wool*, pp. 29 f.

[8] Stromer, "Der innovatorische Rückstand."

ings are more representative for conditions in Europe as a whole than if we had based our analysis on data from well-developed regions such as the Netherlands or Italy alone.

Despite the overall backward character of the Hanseatic area, coins do seem to have been shipped speculatively. Merchants did not make a fundamental distinction between them and other commodities, calling exchange transactions the "purchase" and "sale" of coins. In a similar vein, the use of bills of exchange was called "*overkof*," which can be translated as "sale at a distance."[9] Moreover, merchants active on international markets can be assumed to have been well aware of the bullion content of the coins they were handling. In view of this, it would be more than surprising if they had not tried to profit from arbitrage on the money market. Hence, the essential conditions for the application of our method were given in the time and area that we examine.

MEDIEVAL EXCHANGE RATES AND COINAGE

In this section, we discuss three currencies: the Flemish pound grote and the marks of Lübeck and Prussia. The pound grote was issued by the counts of Flanders and later by the dukes of Burgundy.[10] The mark of Lübeck was the currency of the Wendish Monetary Union, which, apart from Lübeck, comprised the cities of Hamburg, Lüneburg, and Wismar.[11] Late medieval Prussia was governed by the Teutonic Order, who kept its currency, the mark of Prussia, under close control.[12] As indicated previously, we base our analysis on two types of data: the exchange rates between these currencies on the one hand, and the silver content of the coins issued by the aforementioned authorities on the other. Here, we first discuss the exchange rates.

As a rule, the quality of medieval data leaves much to be desired, and the exchange rates of our currencies, though being better preserved than most other data from this period and region, are no exception. One problem is their uneven distribution over time. As shown by the following table, some decades are covered densely, whereas for others data are scarce or entirely lacking (see Table 1).

However, restricting our attention to periods for which data are plentiful—that is, for Flanders-Lübeck to 1340 to 1440, and for Flanders-Prussia to 1380 to 1450—eliminates much of the problem. For these periods, so many data exist that few interpolations are needed. In fact, for

[9] See for example Mollwo, *Handlungsbuch*, pp. 30, 33; and Lesnikow, *Handelsbücher*, p. 39.
[10] Spufford, *Monetary Problems*; and Munro, *Wool*.
[11] Jesse, *Der Wendische Münzverein*; and Stefke, "Der 'Wendische Münzverein.'"
[12] Volckart, *Münzpolitik*.

TABLE 1
THE DISTRIBUTION OF EXCHANGE RATE QUOTATIONS OVER TIME

	£ Grote – Mark of Lübeck	£ Grote – Mark of Prussia
1330–1339	4	—
1340–1349	37	1
1350–1359	19	—
1360–1369	16	5
1370–1379	21	—
1380–1389	11	7
1390–1399	6	6
1400–1409	131	30
1410–1419	71	47
1420–1429	11	34
1430–1439	12	28
1440–1449	4	13
1450–1459	1	6
1460–1469	—	1
1470–1479	8	1
1480–1489	1	—
Total	353	179

Source: Volckart and Wolf, "Estimating Medieval Market Integration."

Flanders-Lübeck during the period 1403 to 1423 we can even construct a series of quarterly data, which allows an in-depth analysis. It is an additional advantage that most of the quotations from this period stem from a single group of closely related sources, i.e., from the account books and commercial correspondence of the Hanseatic merchant Hildebrand Veckinghusen.[13] Veckinghusen's papers yield 197 exchange rate quotations of the pound grote in marks of Lübeck for the first quarter of the fifteenth century. One hundred eighty-four quotations can be dated closely enough to allow their inclusion into an analysis that uses quarterly data, and 131 are from bills of exchange.[14]

We should stress here that we use market rates only, that is, rates that developed under the impact of supply and demand. Occasionally, political authorities imposed exchange rates that obviously differed from those paid on financial markets (that was the point of imposing them); using them would distort our results. Moreover, such rates applied to exchanges that took place at the mint where people had to pay charges and seignorage taxes when they wanted to exchange their money. Such costs figure as additional transaction costs; they are a further source of

[13] Stieda, "Ein Geldgeschäft," *Hansisch-venetianische Handelsbeziehungen*, and, *Hildebrand Veckinghusen*; and Lesnikov, *Handelsbücher*.

[14] Most of the rest of the quotations are from other contemporary account books, see for example Koppmann, *Kämmereirechnungen*, and Sattler, *Handelsrechnungen*. For the full references see Volckart and Wolf, "Estimating Medieval Market Integration."

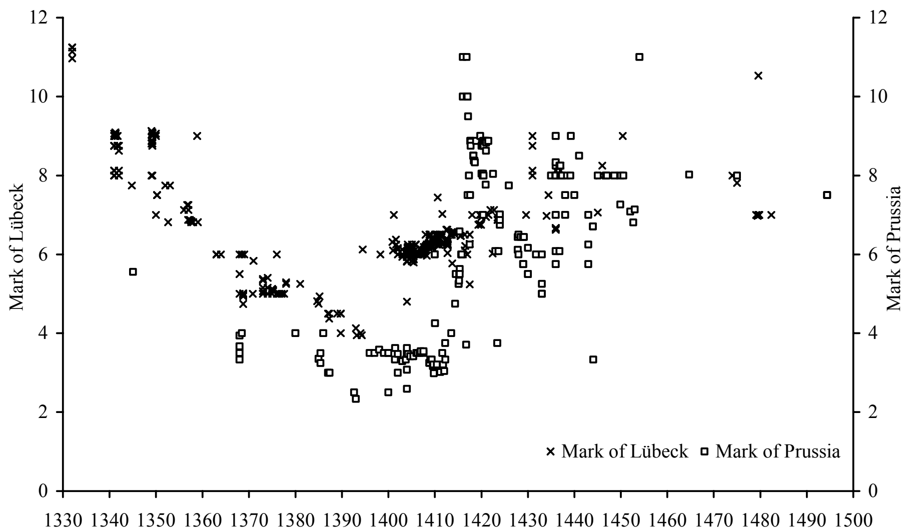

FIGURE 1
NOMINAL EXCHANGE RATE OF THE POUND GROTE AND THE MARKS OF LÜBECK AND PRUSSIA C. 1310–1490

Source: Volckart and Wolf, "Estimating Medieval Market Integration."

distortions, which we want to avoid. Keeping these points in mind, curves of the nominal exchange rates of the pound grote in marks of Lübeck and marks of Prussia in the time we are discussing can be constructed (see Figure 1).

Apart from the exchange rates, we base our analysis on the silver equivalents of the pound grote and the marks of Lübeck and Prussia. Here, too, some explanations are in order, notably because Raymond de Roover was openly sceptical of attempts to link the bullion content of medieval coins with their exchange rate, claiming that monetary ordinances give no idea of the actual state of the currency at a given time.[15] The ordinances are indeed problematic. As a rule, in the Middle Ages moneyers were unable to produce coins exactly to the standard determined there; they were therefore usually granted a tolerance. However, the observation of this tolerance was closely controled by the political authorities in charge. Thus, the Teutonic Order not only employed assayers, but since 1380 admitted representatives of the Prussian towns to the examination of newly minted coins. This was done in conscious imitation of measures taken in the Netherlands.[16] The Wendish Union, each of whose members faced incentives to profit from Gresham's Law by

[15] De Roover, *Bruges Money Market*, p. 38.
[16] Volckart, *Münzpolitik*, p. 194.

producing substandard coins, employed joint inspectors.[17] On the whole, we can therefore assume that the money that left the mints corresponded quite closely to the standard set down in the ordinances.[18]

However, over time coins became worn down, losing some of their weight and precious metal. This problem has been extensively discussed in the literature, but in our context it is not as serious as it seems to be at first glance.[19] Wear and tear may have influenced prices and, by implication, exchange rates in monetary systems based on periodic recoinages. In Flanders, however, output-statistics show that new coins were issued more or less continually, and in Prussia and the Wendish Cities, from where only fragmentary mint-accounts have been preserved, the numbers of dies worn out at the mints suggest that production was continuously sustained, too.[20] Hence, we can assume that the share of defaced coins was about equally large in all three currencies that we are examining, so that the effects of wear and tear in Flanders, the Wendish cities, and Prussia cancelled each other out.

Apart from monetary ordinances there are other sources that contain information about the coins' content of specie. Occasionally, contemporary political authorities assayed the money in circulation, and, increasingly, medieval coins are being chemically analyzed in the context of modern research.[21] Such information is, of course, particularly valuable in cases where neither ordinances nor mint-accounts have been preserved, as for example in Prussia for the years 1396–1403 and 1407–1416. This is all the more important because the debased coins issued by the Teutonic Order between its defeat at Tannenberg/Grunwald in 1410 and the well-documented re-enforcement of the coinage in 1416 dominated in circulation at least until the middle of the fifteenth century, the Prussian administration not even attempting to withdraw them.[22] In this case, an assay taken in 1439 provides the information about the bullion content of the debased pre-re-enforcement money.[23] Figure 2 shows how the silver equivalents of the currencies we are examining developed.

[17] Ropp, *Hanserecesse*, vol. 4, p. 209.

[18] As for the silver content, the data for Flanders are given in van Werveke, "De economische en sociale gevolgen," p. 244; Munro, *Wool*, p. 211; and Blockmans and Blockmans, "Devaluation," pp. 83, 89. The data for the Wendish Union are from Jesse, *Der Wendische Münzverein*, pp. 209 ff.; and those for Prussia from Volckart, *Münzpolitik*, p. 435.

[19] Compare Mayhew, Numismatic Evidence, p. 3; and North, *Geldumlauf*, p. 108.

[20] Munro, "Bullion Flows," p. 136; Jesse, *Der Wendische Münzverein*, pp. 238 ff.; and Volckart, *Münzpolitik*, p. 91.

[21] See for example Kubiak, *Monety*.

[22] Volckart, *Münzpolitik*, p. 91.

[23] Ropp, *Hanserecesse*, vol. 2, p. 225.

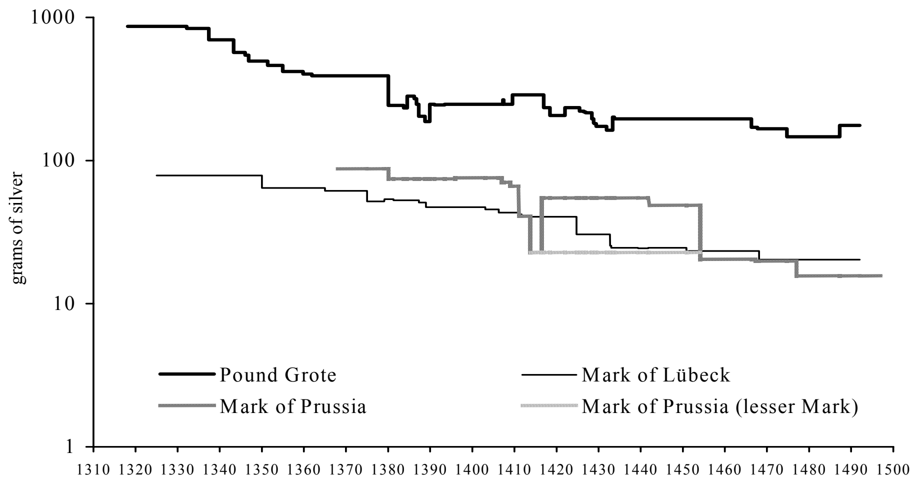

FIGURE 2
SILVER EQUIVALENTS OF THE POUND GROTE AND THE MARKS OF LÜBECK AND PRUSSIA, C. 1320–1490

Sources: See footnote 18.

The Prussian case gives evidence of another problem posed by changes in the standard of the coinage: Whereas after a debasement it was in everybody's interest as quickly as possible to exchange his old coins for a larger nominal sum of new ones, after a re-enforcement of the coinage the old money tended to continue to circulate. No one was interested in taking it to the mint where he would receive not even the silver-equivalent (the costs of re-minting and seigniorage taxes having been deduced), but an even smaller nominal sum. Prussia, which between the re-enforcement of 1416 and the debasement of 1454 practically had two parallel currencies—the old or "lesser" and the new or "good" mark whose official ratio was 2:1—is an extreme case, but similar problems occurred in Flanders, too.[24]

A final factor, which should be taken into account, is the distance of the exchange transaction to the place of origin of the coins involved. It seems reasonable to assume that abroad, older coins continued to circulate some time after they had been replaced by new ones at home. Hence, we need to make a distinction between several factors when we want to determine the delay between the official change in the standard of coinage and the time when the new coins dominated circulation: the

[24] Volckart, *Münzpolitik*, pp. 97 f.; for an example of the parallel circulation of old and new money in Flanders see Sattler, *Handelsrechnungen*, p. 517.

TABLE 2
TIME LAGS BETWEEN CHANGES IN THE STANDARD OF A CURRENCY AND THE USE OF THE NEW COINS

	Debasement		Re-enforcement	
Place of exchange:	Home	Abroad	Home	Abroad
Pound Grote	0 years	1 year	1 year	2 years
Mark of Lübeck	0 years	1 year	1 year	2 years
Mark of Prussia	1 year	2 years	—	—

Note: For the period 1416–1454, we found a single quotation for the pound grote in marks of Prussia which applied to the new or good mark. All others were for the old or lesser mark.

direction of the change of standard (debasement or re-enforcement), the administrative abilities of the authority that issued the currency (relatively good in Flanders and in the Wendish cities, bad in Prussia), and whether the coins were exchanged at the place where they had been minted or abroad. In calculating the exchange rate that would have corresponded to silver parity, we consequently need to take a time-lag into account. Table 2 lists our assumptions.

MEASURING MONETARY INTEGRATION

Econometric Model Framework

In this section we estimate the degree to which money markets between Flanders, Lübeck, and Prussia were integrated. The challenge to estimating integration is to account for the nonlinearity of the adjustment process. Arbitrage between locations will only take place if expected gains are sufficiently high to cover the costs of information, insurance, and shipment, which define the silver points. We consequently expect that the behavior of nominal exchange rates at which coins were traded between Flanders, Lübeck, and Prussia will show a regime switch once exchange rates deviate far enough from the underlying rate of their silver contents. For exchange rate deviations within the silver points, the nominal rate should behave like a stationary disturbance term. By contrast, for deviations outside the points, we expect a nonstationary behavior of the series, i.e., an adjustment process back towards the underlying rate of silver contents. As shown by Maurice Obstfeld and Alan M. Taylor, the appropriate framework for modeling such a process is that of a threshold autoregression (TAR) model.[25] In what follows, we estimate a TAR specification that can be directly derived

[25] Obstfeld and Taylor, "Nonlinear Aspects"; and Taylor, "Potential Pitfalls."

from a simple structural model of the medieval money market.[26] The model delivers a standard three-regime TAR formulation for the dynamics of exchange rate deviations: we expect to find a regime of silver exports, of silver imports, and of random fluctuations within the limits set by transport, insurance, and information costs. We define X_t as the percentage deviation between the nominal exchange rate E_t and the silver parity between coins E_t^{par}

$$X_t = E_t - E_t^{par} \tag{1}$$

We expect the behavior of exchange rates to be driven by deviations from parity relative to the costs of arbitrage. Specifically, we estimate

$$\Delta X_t = \begin{cases} \alpha(X_{t-1} - \tau) - \beta\Delta E_t^{par} + \beta\upsilon_t & when X_{t-1} > \tau \\ \upsilon_t - \Delta E_t^{par} & when |S_{t-1}| \leq -\tau \\ -\alpha(X_{t-1} - \tau) - \beta\Delta E_t^{par} + \beta\upsilon_t & when - X_{t-1} > \tau \end{cases} \tag{2}$$

where α, β, and τ are parameters to be estimated. The parameter τ captures the effect of arbitrage costs expressed per silver unit. When arbitrage in the money market is unprofitable, the deviation between the observed exchange rate and silver parity behaves like a stationary disturbance term, υ_t. The key prediction of the model is that if the exchange rate exceeds silver parity by more than the limit set by τ, arbitrage in silver will force it to revert to within those limits. The speed of that adjustment process is estimated by the coefficient α. When derived from a structural model, it can be shown that this speed of adjustment depends on the structural elements of the economy such as costs of seignorage and on nonlinear parts of the arbitrage costs due to possible risk-aversion of traders.[27]

Estimation Strategy and Pre-Tests

Because our task of estimating a nonlinear TAR model is rather demanding in terms of the quality of the data, we will focus on the years between 1385 and 1450 for which they are most complete and available for both Flanders-Lübeck and Flanders-Prussia. Moreover, we also estimate the model based on quarterly data, which is available for Flanders-Lübeck in the period 1403 to 1423. As a general rule, we always

[26] Volckart and Wolf, "Estimating Medieval Market Integration"; see also Canjels, Prakash-Canjels, and Taylor, "Measuring Market Integration."
[27] Volckart and Wolf, "Estimating Medieval Market Integration."

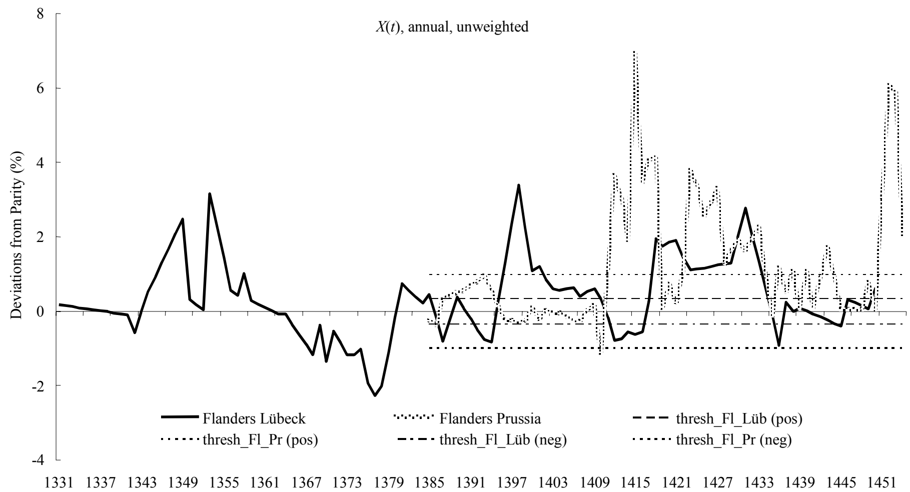

FIGURE 3
UNWEIGHTED SERIES OF ANNUAL DEVIATIONS FROM PAR, FLANDERS-LÜBECK, 1341–1450, AND FLANDERS-PRUSSIA, 1385–1454

Source: Volckart and Wolf, "Estimating Medieval Market Integration."

convert our observations into a continous series of data points where we use simple averages for periods with more than one observation and interpolation techniques to deal with missing data. In order to account for the fact that we have more information for some years than for others, we weight the resulting annual (or quarterly) time series by the number of observations for each year (or quarter).

Before we proceed to the estimation of our model, we will first check whether X_t, the unweighted annual series of exchange rate deviations from par, is a stationary process or whether it contains a unit root. With a unit root, we would expect to see some trending behavior over the whole period, which would be incompatible with the basic implication of our model that large deviations from par should trigger an adjustment process due to arbitrage in silver. Figure 3 plots the annual series of X_t over time, and Figure 4 plots the quarterely data for the early fifteenth century.

The annual series do indeed give a realistic picture of exchange rate dynamics insofar as there is little evidence of higher frequency adjustment processes that would be undetectable from annual averages.[28] Next, the graphs do not suggest the presence of unit roots. Both the annual and the quarterly data suggest that there were several large deviations from par, but reverse adjustments always took place. Still, there is an important difference between the cases of Lübeck and Prussia: Although

[28] See Taylor, "Potential Pitfalls."

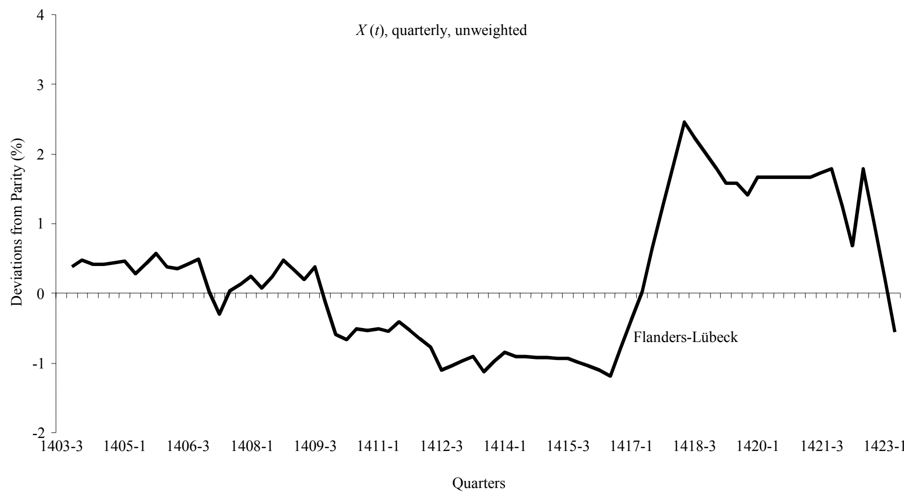

FIGURE 4
QUARTERLY DEVIATIONS FROM PAR, FLANDERS-LÜBECK, 1403–1423

Source: Volckart and Wolf, "Estimating Medieval Market Integration."

the exchange rates of both marks for the pound regularly diverted to within the silver points, in the Prussian case deviations tended to be in one direction only, indicating that the mark of Prussia was consistently undervalued. This seems to have been due to an imbalance of trade, i.e., to the fact that Prussia imported more from Flanders than she exported. Such an imbalance may well have persisted over several decades, all the more so as it was probably made up by a favorable balance of payments vis-à-vis Poland and Hungary, from where much of the silver used in Prussia came.[29] On the whole, however, all series seem to have behaved like stationary processes, which is in line with our TAR specification.[30] However, in line with the model's prediction that adjustment takes place only if the deviations exceed the silver points and arbitrage starts to pay off, both series do seem to follow a random walk up to certain points where reversal takes place. Given these characteristics of our data, we can proceed to estimate the econometric TAR model implied

[29] Volckart, *Münzpolitik*, pp. 35, 49; compare Bernholz, "Bedeutung der Geschichte," pp. 144 f. There is quite a lot of anecdotal evidence for shipments of silver from Prussia to the West: Stieda, *Hildebrand Veckinghusen*, pp. 183 f., 186 f., 198 f., 201 ff., 255 f. However, we did not find any evidence for shipments from Flanders or Lübeck toward Prussia.

[30] Both an Augmented Dickey-Fuller and a Phillips-Perron test clearly reject the null-hypothesis of a unit root: for Flanders-Lübeck annual: ADF statistic: –3.21, McKinnon value (1 percent): –2.58, PP statistic: –3.21, McKinnon critical value (1 percent): –2.58. For Flanders-Prussia annual: ADF statistic: –2.82, McKinnon value (1 percent): –2.60, PP statistic: –2.76, McKinnon critical value (1 percent): –2.60. For Flanders-Lübeck quarterly: ADF statistic: –1.690, McKinnon value (1 percent): –1.614, PP statistic: –1.655, McKinnon critical value (10 percent): –1.614.

by our economic model. We estimate our model in a two-step procedure, using Conditional Least Squares (CLS) following Eugene Canjels et al.[31] In a first step we estimate the points of regime switch and in a second step the parameters in the non-random-walk regimes with OLS, given the points of regime switch. That is, we use OLS to estimate a specification of the form

$$\Delta X_t \cdot indicator = Pos \cdot (C_1 X_{t-1} - C_2) - Neg \cdot (C_1 X_{t-1} - C_2) + C_3 \Delta E_t^{par} + \upsilon_t \quad (3)$$

where *indicator* is a variable that takes on the value of one if we are outside the intermediate random-walk regime, and has no value otherwise, while *Pos* and *Neg* indicate silver export and import regimes. The parameters C_1, C_2, and C_3 are equivalent to the model parameters α, τ, and β respectively. According to our model, and as usual in TAR models, the points of regime switch are identified by the fact that within these points the series should behave like a (nonstationary) random walk.[32] Hence, we first represent the weighted series as a random walk and estimate deviations from random-walk behavior in the form $X_t = X_{t-1} - E_t^{par} + \varepsilon_t$. The estimated series of errors from that series can be used to create an indicator variable for regime switch: large (positive or negative) deviations indicate that the series cannot be represented any more by a random-walk regime, suggesting that one of the other two regimes applies.[33] Accordingly, we create an indicator series *indicator*, which takes on the value of one if we are outside the intermediate random-walk regime, and has no value otherwise. Next, we use *indicator* to estimate our model outside the random-walk regime. Again, we do this based on the weighted series using simple OLS. To account for systematic differences between regimes of positive and negative deviations we use two dummy variables $Neg = 1$ *if* $X_t < 0$ and $Pos = 1 - Neg$. Table 3 compares the average deviation X_t under the three regimes and the numbers of observation under each of the three regimes.

In all three cases, about half of the observations are estimated to be outside the random-walk regime. As expected, we see that the average of absolute deviations under a random-walk regime is lower than under the other two regimes. Overall, we expect to find that changes in deviations ΔX_t are declining in previous deviations X_{t-1}, hence $-1 < C_1 < 0$, and we expect to find some positive threshold level $C_2 > 0$. Finally, we

[31] Canjels, Prakash-Canjels and Taylor, "Measuring Market Integration."
[32] See Balke and Fomby, "Threshold Cointegration"; and Lo and Zivot, "Threshold Cointegration."
[33] Here we define an error larger than the median of absolute errors as "large." We experimented with several other specifications with only very small effects on our results.

TABLE 3
AVERAGE DEVIATIONS AND NUMBER OF OBSERVATIONS IN EACH OF THE THREE REGIMES, ANNUAL AND QUARTERLY DATA

	Random Walk		Silver Export		Silver Import	
	Average abs(X_t)	N	Average abs(X_t)	N	Average abs(X_t)	N
Flanders-Lübeck	0.11	47	0.55	25	0.80	38
Flanders-Prussia	0.19	37	1.11	3	1.10	31
Flanders-Lübeck	0.61	31	0.76	13	1.12	34

Note: See the text.

expect to find $C_3 < 0$ as implied by our economic model. The next section contains the results of that exercise and our interpretation.

Empirical Results and Interpretation

Our procedure to estimate the points of regime switch delivered quite reasonable results, so that we estimate our model as described in equation 3. We first assume symmetry across regimes; next we relax this to allow for regime-specific coefficients (see Table 4).

Most of the estimated coefficients are significant at a 5 percent level, and, as predicted, we always find a negative adjustment parameter C_1 and a positive threshold C_2, which seems of reasonable magnitude given the average deviations under the random-walk regimes in both our cases. Also, the coefficient on parity changes has the expected negative sign. Next, we repeat the estimation without the assumption of symmetry between the silver import and silver export regimes. In the case of Flanders-Prussia in particular, Figure 3 suggests some significant differences. Two findings stand out. First, the statistical significance of the adjustment coefficients is much lower, which is no surprise given the small number of observations under some of the regimes. Second, given lower significance, the estimated adjustment under a silver import regime in the case of Flanders-Lübeck does not appear to have taken place much faster than in the case of Flanders-Prussia. However, the estimated threshold levels for Flanders-Lübeck are still much lower, indicating that adjustment set in earlier.

How shall we interpret these findings? As expected, the money market between Flanders and Lübeck was much better integrated than the market between Flanders and remote Prussia. The estimate C_2 for transport and information costs (τ in the economic model) is much higher for the latter case. And the estimates C_1 indicate a significantly higher speed of adjustment between Flanders and Lübeck than between Flanders

TABLE 4
ESTIMATION OF THRESHOLDS AND ADJUSTMENT PARAMETERS, ANNUAL DATA

Symmetry

	Flanders-Lübeck, 1385–1450			Flanders-Prussia 1385–1450		
	Coefficient	*t*-stat	Prob.	Coefficient	*t*-stat	Prob.
C(1)	–0.639	–3.493	0.005	–0.326	–2.071	0.048
C(2)	0.344	2.717	0.011	0.988	4.094	0.000
C(3)	–1.473	–1.789	0.083	–0.355	–1.631	0.114
Adjusted *R*-squared	0.386			0.548		
S.E. of regression	0.628			1.017		
Sum squared residual	12.218			27.90		

No Symmetry

	Flanders-Lübeck, 1385–1450			Flanders-Prussia 1385–1450		
	Coefficient	*t*-stat	Prob.	Coefficient	*t*-stat	Prob.
C(1.1)	–0.327	–1.555	0.131	–0.319	–1.921	0.066
C(1.2)	–0.053	–0.267	0.790	0.022	0.083	0.935
C(2.1)	0.036	0.188	0.852	0.955	3.765	0.001
C(2.2)	0.583	14.497	0.000	1.344	7.269	0.000
C(3)	–1.117	–1.542	0.134	–0.413	–1.732	0.096
Adjusted *R*-squared	0.563			0.520		
S.E. of regression	0.529			1.048		
Sum squared residual	8.124			27.442		

Note: See the text.

and Prussia. In order to interpret the estimated adjustment parameters, it is useful to express them in terms of a half-life time. We rearrange equation 3 to get

$$X_t = \rho X_{t-1} - \alpha\tau + \beta\upsilon_t, \quad \text{where } \rho = 1 + \alpha \tag{4}$$

Hence, the implied half-life can be calculated as $Time_{T/2} = \frac{\ln(0.5)}{\ln(\rho)}$. Our estimates imply that between 1385 and 1450, it took on average about eight months until arbitrage in silver reduced a deviation outside the threshold bands between Lübeck and Flanders by 50 percent. During the same period it took on average about 21 months to reduce a deviation between Prussia and Flanders.

Finally, all these estimates suffer from the fact that we use annual data, which implies that adjustment processes with a half-life of less than six months cannot possibly be identified.[34] However, we can re-estimate our model on the basis of quarterly data for Flanders-Lübeck

[34] Compare Taylor, "Potential Pitfalls."

TABLE 5
ESTIMATION OF THRESHOLDS AND ADJUSTMENT PARAMETERS,
FLANDERS-LÜBECK, 1403–1423, QUARTERLY DATA,
NO-SYMMETRY ASSUMPTION

	Symmetry			No Symmetry		
	Coefficient	*t*-stat	Prob.	Coefficient	*t*-stat	Prob.
C(1)	–0.216	–4.578	0.000			
C(1.1)				–0.221	–4.329	0.000
C(1.2)				0.063	0.690	0.494
C(2)	0.122	2.658	0.019			
C(2.1)				0.119	1.752	0.087
C(2.2)				0.338	5.366	0.000
C(3)	–0.226	–2.849	0.007	–0.149	–2.626	0.012
Adjusted *R*-squared	0.614			0.629		
S.E. of regression	0.255			0.250		
Sum squared residual	2.860			2.626		

Note: See the text.

1403–1423. Figure 4 does not suggest much of a change, given that we do not observe much high-frequency variation in exchange-rate deviations. Table 5 gives the estimation results under the assumption of symmetry and without the symmetry assumption.

The fit of the model has improved, and for the symmetric case all coefficients are statistically significant at the 5 percent level. Without the assumption of symmetry, only the adjustment coefficient under a silver import regime is estimated to be statistically different from zero. Interestingly, both that coefficient and the coefficient under the symmetry assumption imply a half-life of $Time_{T/2} = \frac{\ln(0.5)}{\ln(\rho)} \approx 2.8$ quarters, that is, of about eight months. This is perfectly in line with our estimate based on the annual series and again indicates that higher-frequency adjustment was—at least during the period 1403–1423—not taking place. Given this, our estimated half-lifes of between eight and 21 months based on annual data can be compared with those implied by Canjels et al.'s estimation for the Gold Standard period.[35] Given their estimate of the adjustment parameter, it took only about six days to reduce a deviation between New York and London between 1879 and 1913. Also, all our estimates C_2 of the silver points (the τ in the model) are in an order of magnitude above those estimated by Canjels et al. for that period.[36] Although we cannot corroborate our findings with direct evidence of the costs of shipping silver, we think that this result is rather intuitive. Ad-

[35] Canjels, Prakash-Canjels, and Taylor, "Measuring Market Integration."
[36] Canjels, Prakash-Canjels, and Taylor, "Measuring Market Integration."

justment in the silver market was massively slower during the late Middle Ages than adjustment in the gold market in the late nineteenth century.

CONCLUSION

Financial markets integrate more easily than those for other goods. In the context of research done on medieval market integration, it therefore makes sense to pay special attention to them: they can be used as a benchmark for other markets that arguably could not be better-integrated than they. In this article, we study late medieval financial integration not only on the basis of a new data-set that comprises exchange rates from a hitherto neglected area, but also with the help of the recently developed TAR-modelling approach.[37] Our method yields plausible results for medieval market integration. As expected, markets between Flanders and Lübeck worked much better than markets between Flanders and Prussia. We found that during the fourteenth and fifteenth centuries it took about eight months until the market adjusted for deviations above the silver points in the case of Flanders and Lübeck, and confirmed that result using quarterly data for the period 1403–1423. In the case of Flanders and Prussia it took roughly twice as long. To compare, transatlantic gold trade in the nineteenth century needed just six days to wipe out deviations from the gold points.[38] Moreover, our estimates of medieval silver points are an order of magnitude above the nineteenth-century gold points, suggesting much higher costs of transportation and information. Compared with the traditional approaches to estimating market integration, our method has distinct advantages: It requires relatively few data and is still able to yield precise results.

[37] Spufford's "Handbook of Medieval Exchange" contains few data from the Hanseatic area.
[38] Compare Canjels, Prakash-Canjels, and Taylor, "Measuring Market Integration."

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