Time-varying price discovery in the 18th century

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Abstract

This paper investigates how quickly news is reflected in prices and the information shares for two of the great moneyed companies, the Bank of England and the East India Company, during the eighteenth century. These two English companies were cross-listed on the Amsterdam stock exchange and news between the capitals flowed mainly via the use of boats that transported mail. We examine in detail the historical context surrounding the defining events of the period, and use these as a guide to how the data should be analysed. We show that both trading venues contributed to price discovery, but the London venue was significantly more important for both stocks, although its information share gradually declined over time.

Key Words: Arbitrage, information shares, cross-listed stocks, historical finance, 18th century stocks.

JEL Classification Codes: N230, G140, C320

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1 Introduction

There is a large and growing modern market microstructure literature on price discovery, defined as the process by and the speed with which new information is reflected in the prices of traded assets. It is sometimes the case that one security trades simultaneously on two or more markets, which is termed cross-listing, in particular with stocks. In such circumstances, it is of interest to determine how important each of the trading venues is in contributing to the movements in prices across these venues as a whole. In a particularly significant study, Hasbrouck (1995) proposes a method to examine the relative weight of each market’s price discovery function in terms of the proportional contribution of that market’s price changes to an overall underlying but unobservable price change common to all markets. The information share for a given market is then essentially defined as the proportion of the variance of the common stochastic trend that the market’s innovations explain, and is calculated from a vector error correction (VEC) model for a set of cointegrated price series.

Since its development, the information shares approach has been extended and successfully applied to cross-listed stocks (for example, Pascual et al., 2006 and Huang, 2002 for the US; and Chan et al., 2007 for China), government bonds (e.g., Upper and Werner, 2002 for Germany; and Campbell and Hendry, 2007 for the US and Canada) and the market for carbon emissions (Mizrach and Otsubo, 2011).

Although these sophisticated techniques for examining price discovery were not available until very recently, it is of interest to consider whether the markets during the eighteenth century were able to efficiently incorporate information and to investigate how news flowed from one market to another. We will analyse two shares that were cross-listed on the London and Amsterdam stock exchanges over the period August 1723 to December 1794, namely the Bank of England (BOE), and East India Company (EIC). Given that these were British companies, it is perhaps to be expected that the key direction of information flow on the underlying activities of the companies would be from London to Amsterdam. News relevant to the cross-listed stocks travelled from Britain to Holland twice per week via “mail packet boats,” for which the British postal service held the monopoly. Koudijs (2009) argues that information may also have travelled in the
opposite direction when news arose on the continent due to Amsterdam’s closer physical proximity to it. News from battlefields on the European continent might reach Amsterdam first, for example, and information from the East Indies may also have originated in Amsterdam if it was brought back from there on Dutch ships, although this happened rarely. Conversely, news from the North American continent would probably have reached London first. Indeed, Neal (1990, p. 163) argues that “information of great influence on the price of English stock reached England before it reached Amsterdam.”

Cross-listing was very useful for these companies since it enabled them to increase the funding available at a key time in their development, and this was almost certainly the first example of cross-listing anywhere in the world. By the end of the seventeenth century, the Dutch had accumulated considerable sums of money that were available for investment. Wilson (1941) argues that demand from Amsterdam helped to support stock prices at times when it was lacking from England. These British companies were attractive to Dutch investors as they provided more potential growth opportunities than those available for their own domestic stocks. In the early 1700s, Dutch investors have been argued to have held up to a third of BOE’s stock (Bowen, 1989), although over the century, interest gradually shifted towards the EIC so that by 1767, the Dutch owned 30% of the EIC (Wright, 1999).

While Dutch investors brought welcome resources, because of the potential for arbitrage and short-term speculative motives rather than long term investment, they later came to be blamed as a contributory factor in causing instability and excessive volatility of the share price. The relatively softer legal regime in Amsterdam encouraged speculative activity to take place there preferentially (Neale, 1990).

To the authors’ knowledge, this study is one of only two sophisticated econometric analyses of the stocks that were cross-listed in London and Amsterdam during the eighteenth century and the first to use cutting edge techniques from the market microstructure literature to investigate the relative information shares of the two centres. The approach that we implement allows for a time-varying estimation of the information shares so that a gauge of price discovery is available for every point in time. This allows us to test for variation within as well as across sub-periods. These results should help to shed new light on the relative role of Amsterdam, and whether in fact Dutch traders can be apportioned
blame for the periodic collapses in prices that ensued.

The only other contribution in this area is the study by Dempster et al. (2000). They examine the extent to which the two markets are integrated using a common features approach. They find that the two markets were indeed highly interlinked, and that price movements across the two markets were matched in both the short and long runs. Dempster et al. argue that, “relevant movements in the market seem to have originated in London...”

The pioneering work on how integrated the Amsterdam and London markets were was conducted by Neal (1987). He shows that the corresponding price series across the two exchanges show very similar patterns and properties. He separates the overall period 1723–1794 into four separate periods of peace (09/08/23 – 19/10/39, 11/11/48 – 14/07/56, 18/02/63 - 04/03/78, 06/12/82 – 22/09/90) and four periods of war (21/10/39 – 23/10/48, 04/08/56 – 05/02/63, 02/03/78 – 20/11/82, 08/10/90 – 19/12/94); he also splits the data into pre- and post Barnard act samples (1723–1737 and 1738–1794). For both BOE and EIC, the differences in the correlations of the price series across the two exchanges are very small; the correlations between the corresponding first differences of prices vary slightly more over the sub-periods but since no formal tests of significance are conducted, it may be that they merely represent standard variations in correlation estimates that would occur over time even if the data generating process remained constant throughout. Neal (1987) then continues to estimate autoregressive moving average (ARMA) models for the changes in prices, arguing that the smaller the optimal number of parameters in the fitted model, the more (weak form) efficient is the market. He finds that the optimal model order is almost always (0,0) - in other words, the best model is a random walk - for both markets, suggesting that information was reflected quickly in price changes for both centres. Only for the EIC traded in Amsterdam does a non-zero model order fit best over the whole period and for many of the sub-periods, particularly during war time. A subsequent regression analysis of the stock price changes on: movements in the foreign exchange rate, whether the stock was trading ex dividend or with

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1While they implement a VEC model model too, they proceed to test for common cycles rather than using the information share approach as we do.

2We employ Neal’s dates for the American War of Independence; however, it is arguable that a longer period could be considered, i.e. 1775-1783.

3This act forbade options and forwards being traded in London (Neal, 1990, p. 150).
dividend in London, and the number of days until the next dividend, led Neal to conclude that the markets were well integrated during the period as well as efficient. This finding corroborated Neal’s (1985) earlier finding that the London, Amsterdam, Paris and New York markets were well integrated in the nineteenth century, and by Harrison (1998), who shows that the distribution of price changes that existed at that time is very similar to that of today.

The remainder of this paper is organised as follows. Section 2 describes the econometric approach that we use to model the movements in stock prices over time and to evaluate the information shares. Section 3 then describes the stock markets considered and Section 4 discusses the results. Finally, Section 5 concludes and offers suggestions for further research.

2 Data Representations

This section provides the models that we use to develop various descriptions of the dynamics of asset prices. Moreover, measures of price discovery are provided within the context of these descriptions and are given by the impact of a shock to a particular market on a competing market.

2.1 The VAR Representation

Consider the following vector autoregressive (VAR) model:

$$y_t = \sum_{i=1}^{p} \Phi_i y_{t-i} + \Psi x_t + \epsilon_t, \quad t = 1, 2, \ldots, T, \quad (1)$$

where $y_t = (y_{1t}, \ldots, y_{mt})'$ is an $m \times 1$ vector of jointly determined dependent variables, $x_t$ is a $q \times 1$ vector of deterministic/exogenous variables, $\{\Phi_i, i = 1, \ldots, p\}$ and $\Psi$ are $m \times m$ and $m \times q$ coefficient matrices, and $\epsilon_t = (\epsilon_{1t}, \ldots, \epsilon_{mt})'$ is an $m \times 1$ vector of suitably defined error terms such that $\epsilon_t \sim \text{IN}(0, \Sigma)$, with $\Sigma = \{\sigma_{ij}, i, j = 1, \ldots, m\}$. In our application, the only exogenous variables are a set of monthly seasonal dummy variables.

Under the assumption that $y_t$ is covariance-stationary, (1) can be expressed as an
infinite moving average process,

\[ y_t = \sum_{i=0}^{\infty} A_i \epsilon_{t-i} + \sum_{i=0}^{\infty} G_i x_{t-i}, \]  

(2)

where \( A_i \) is obtained using the following recursion:

\[ A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \ldots + \Phi_p A_{i-p}, \]  

(3)

with \( A_0 = I_m, A_i = 0 \) for \( i < 0 \), and \( G_i = A_i \Psi \).

Within this framework, the \( m \times 1 \) vector of the generalised impulse response function of a shock to the \( j \)th equation on \( y_{t+n} \) is given by

\[ GIRF_{j;n} = \sigma_{jj}^{-1/2} A_n \Sigma e_j, \]  

(4)

where \( e_j \) is an \( m \times 1 \) selection vector. See Pesaran and Shin (1998) for further details of generalised impulse response functions.

2.2 The VEC Representation

Now consider the following vector error correction (VEC) model associated with a system of cointegrated asset prices:

\[ \Delta y_t = -\Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \Pi \Lambda x_t + \epsilon_t, \]  

(5)

where \( \Pi = \alpha \beta' \), \( \alpha \) is an \( m \times r \) matrix of adjustment coefficients, \( \beta \) is an \( m \times r \) matrix such that the \( r \times 1 \) vector \( z_t = \beta' y_t \) is stationary, and \( 1 \leq r < m \). The coefficients in (1) can be obtained using the coefficients in (5) as follows:

\[ \Phi_i = \begin{cases} 
I_m - \Pi + \Gamma_1, & \text{for } i = 1, \\
\Gamma_i - \Gamma_{i-1}, & \text{for } i = 2, \ldots, p - 1, \\
-\Gamma_{p-1}, & \text{for } i = p, 
\end{cases} \]  

(6)
where all previous notation is maintained.

Under the assumption that $\Delta y_t$ is covariance-stationary, (5) can be expressed as follows:

$$\Delta y_t = \sum_{i=0}^{\infty} C_i \epsilon_{t-i} + \sum_{i=0}^{\infty} C_i \Pi \Lambda x_{t-i}. \quad (7)$$

Moreover, it is possible to show that the generalised impulse response functions of a shock to the $j$th equation on $y_{t+n}$ are respectively given by

$$\text{GIRF}_{j,n} = \sigma_{jj}^{-1/2} B_n \Sigma e_j, \quad (8)$$

where

$$B_i = \sum_{j=0}^{i} C_j, \quad (9)$$

is the ‘cumulative effect’ matrix obtained using the following recursion:

$$B_i = \Phi_1 B_{i-1} + \Phi_2 B_{i-2} + \ldots + \Phi_p B_{i-p}, \quad (10)$$

with $B_0 = I_m$, and $B_i = 0$ for $i < 0$.

### 2.3 The Common Stochastic Trend Representation

It is possible to rearrange (7) as follows:

$$y_t = B_\infty \sum_{i=0}^{t} \epsilon_j + \nu_t, \quad (11)$$

where $\nu_t$ is a suitably defined stationary error term. Under the assumption that the contents of $y_t$ are cointegrated, all rows in $B_\infty$ are identical (we denote $D$ as the $m \times 1$ common row vector of $B_\infty$). Furthermore, given this implication, it is possible to show that (11) can be written in terms of the Stock and Watson (1988) common stochastic trend representation,

$$y_t = m_t + \nu_t, \quad (12)$$

where

$$m_t = m_{t-1} + D' \epsilon_t. \quad (13)$$
Within the context of cointegrated prices of equivalent assets traded in \( m \) markets, this common stochastic trend can be interpreted as the unobservable efficient price (Hasbrouck, 1995), with \( D \) measuring the contribution of each market to changes in the efficient price.

Given the above reasoning, the estimated generalised impulse response functions of a shock to the \( j \)th equation on the efficient price can be defined as follows:

\[
\text{GIRF}_j = \hat{\sigma}_{jj}^{-1/2} \hat{D}' \hat{\Sigma} e_j. \tag{14}
\]

Alternatively, one may wish to follow Hasbrouck (1995) and consider the squared relative shock magnitudes, that is, the information share given by

\[
\hat{I}_j = \left( \hat{\sigma}_{jj}^{-1/2} \hat{D}' \hat{\Sigma} e_j \right)^2 / \sum_{j=1}^{m} \left( \hat{\sigma}_{jj}^{-1/2} \hat{D}' \hat{\Sigma} e_j \right)^2, \tag{15}
\]

where all previous notation is maintained.

### 2.4 Time-varying information share

It is unreasonable to assume that the above information share remains constant over time. To relax this particular assumption we allow the coefficients in the VEC model to time-vary. In particular, we assume that the following time-varying VEC model:

\[
\Delta y_t = -\Pi_t y_{t-1} + \sum_{i=1}^{p-1} \Gamma_{i,t} \Delta y_{t-i} + \Pi_t \Lambda_t x_t + \epsilon_t, \quad t \in \{1, \ldots, T\}, \tag{16}
\]

where \( \Pi_t = \alpha_t \beta' \). Given the above dynamics, the recursively estimated fitted returns are given by

\[
\Delta y_s = -\hat{\Pi}_s y_{s-1} + \sum_{i=1}^{p-1} \hat{\Gamma}_{i,s} \Delta y_{s-i} + \hat{\Pi}_s \hat{\Lambda}_s x_s, \quad s \in \{S, \ldots, T\}. \tag{17}
\]

In this instance, the parameter vector \( \theta_s \equiv (\text{vec}(\hat{\Pi}_s)', \text{vec}(\hat{\Gamma}_{i,s})', \text{vec}(\hat{\Lambda}_s)')' \) represents the solution to the following optimisation problem:

\[
\theta_s = \underset{\theta_s}{\text{argmin}} -\frac{1}{2} \ln |W_s|, \tag{18}
\]
where
\[ W_s = \frac{1}{r} \sum_{r=1}^{s} \omega_r \epsilon_r' \epsilon_r', \]  
(19)
and \( \omega_r \) is given by
\[ \omega_r = \exp[-\delta(s - r)]. \]  
(20)
By using this particular non-uniform weighting function one can allow the coefficients to change in a speedy fashion (cf. recursive estimation), with recent errors receiving heavier weights than less recent errors as dictated by the value of the rate of decay parameter \( \delta \geq 0 \).

The time-varying coefficients estimated above are then used to calculate a time-varying information share measure, with time-invariant coefficients replaced with the time-varying coefficients to give
\[ \hat{\mathbf{I}}_{\gamma,s} = \left( \hat{\sigma}_{jj,s}^{-1/2} \hat{\mathbf{D}}_s' \hat{\Sigma}_s e_j \right)^2 \left/ \sum_{j=1}^{m} \left( \hat{\sigma}_{jj,s}^{-1/2} \hat{\mathbf{D}}'_s \hat{\Sigma}_s e_j \right)^2 \right., \]  
(21)
where \( \mathbf{D}_s \) is the common row vector of \( \mathbf{B}_{\infty,s} \) obtained via the following recursion:
\[ \mathbf{B}_{i,s} = \Phi_{1,s} \mathbf{B}_{i-1,s} + \Phi_{2,s} \mathbf{B}_{i-2,s} + \ldots + \Phi_{p,s} \mathbf{B}_{i-p,s}, \]  
(22)
with \( \mathbf{B}_{0,s} = \mathbf{I}_m \), and \( \mathbf{B}_{i,s} = 0 \) for \( i < 0 \), and
\[ \Phi_{i,s} = \begin{cases} 
\mathbf{I}_m - \Pi_s + \Gamma_{1,s}, & \text{for } i = 1, \\
\Gamma_{i,s} - \Gamma_{i-1,s}, & \text{for } i = 2, \ldots, p - 1, \\
-\Gamma_{p-1,s}, & \text{for } i = p,
\end{cases} \]  
(23)
and residual heteroscedasticity to account for by estimating the residual variance-covariance matrix as follows:
\[ \hat{\Sigma}_s = \frac{1}{r} \sum_{r=1}^{s} \omega_r \hat{\epsilon}_r \hat{\epsilon}_r', \]  
(24)
with \( \hat{\sigma}_{jj,s} \) denoting the diagonal element of \( \hat{\Sigma}_s \).
3 An application to Eighteenth Century Cross-Listed Stocks

3.1 The Markets

Whilst Eighteenth century stock exchanges in London and Amsterdam were technically far removed from modern stock markets, they had similar features that support the current study. For instance, Neal (1990, p. 120) argues that “the evaluations of the equity of each joint-stock company made by investors trading and speculating in their shares on the stock exchanges of London and Amsterdam were much the same as the evaluations of corporate enterprises that are seen in modern stock markets.”

Rather than being concentrated on one trading floor (either electronic or physically), Dale (2004, pp. 26-39) colourfully describes how the London Stock Exchange was focused in one particular precinct in the City of London, but with business being conducted in a variety of coffee houses in and around Exchange Alley. Thus the trading was not central and settlement was required to be done in person at the premises of each company. The market was given liquidity by “stockjobbers,” “acting as principals, taking stock into their own books and quoting both a buying and selling price” (Dale, 2004, p. 27). Also, stocks could be purchased in a variety of ways including arrangements similar to today’s contracts for spot purchase, forward purchase, call options, put options, and repos.

Both the Amsterdam and London exchanges also had a number of differences from modern stock exchanges. For instance, an absence of both institutional investors and of a financial regulator are obvious key distinctions that may affect the way that the market functions and the extent to which prices efficiently reflect information. Despite these differences, as we will show below, the main features of the price movements are very similar to those that might be expected from current markets.

3.2 Data

We consider the prices of two shares cross-listed on the London and Amsterdam stock exchanges over the period August 1723 to December 1794, viz. Bank of England (BOE), and East India Company (EIC) shares. These two are the largest of the “great moneyed
companies,” so called because they financed the reorganisation of the national debt in the eighteenth century by holding significant amounts of government debt securities (see Shea, 2000). The data are sampled on a bi-weekly basis.

While it is clear that the securities traded in London were stocks, it is less certain what was the precise status of those traded in Amsterdam. It seems most likely that they were stock futures contracts as most securities were (see Neal, 1990, and van Dillen, 1931). An Act of Parliament, Barnard’s Act, was passed in 1733 and sought to ban trading in futures, although it is not clear that the Act was successful, and trading in Amsterdam appeared to continue largely as before. van Dillen (1931) suggests that the time-series from 1723 to 1794 may comprise a mixture of both spot and futures prices. Neal (1990) argues that prices were on average no higher in Amsterdam and no more volatile, which further complicates the issue of precisely what type of security the Dutch assets were.

As Neal (1990) notes, whether the Amsterdam securities were stocks or futures will have a key implication concerning the treatment of dividends. While the divided values are available, the dates at which the stocks became ex dividend are not, and therefore, rather than correct for the effect of dividends directly, we implement a procedure that will automatically adjust for it. More specifically, by allowing all coefficients in the model to vary over time and by using a set of monthly dummy variables, we can account for any seasonality in the mis-pricing series due to unobservable maturity or dividend effects. The original source of the data is “the Course of the Exchange,” which is a printed list of the prices of stocks traded in London together with a number of exchange rates and the prices of several commodities. The list was made by John Castaing, a stock broker, and was printed twice per week from 1698, eventually becoming the price list of the London stock exchange. The data for the British stocks on the Amsterdam market were originally obtained from the Amsterdamsche Courant, a Dutch newspaper, but this information was only transcribed every two weeks by van Dillen (1931) for the period 1723-1794, which limits the length and frequency of analysis that can be conducted on

4While the original data source contains price data for the South Sea company as well as the BOE and EIC, we do not use this series since it is very thinly traded after the bubble of 1720 and so is likely to lead to misleading results. There were around 150 companies that were publicly quoted at some point between 1690 and 1834 (see Shea, 2000), but most of these were extremely small and with very incomplete records making them not amenable to formal statistical analysis.

5Indeed, as we show below, the proportion of price discovery attributable to Amsterdam rose slightly rather than falling.
the cross-listed stocks. We obtained the data for both the London and Amsterdam prices from the Economic and Social Data Service.\footnote{see \url{http://www.esds.ac.uk/about/about.asp}. The title of the archive is SN 3211.}

Historically, while the markets appeared to function regardless, this was a period of considerable turmoil as a result of a series of wars and financial crises. Simply put, in terms of British involvement in warfare, the first major conflict was the War of Austrian Succession (1739-48), in which Britain was later allied with the Dutch republic and Austria against France, Prussia and Spain. The theatre of war involved conflict with France in North America and India. In the Seven Years War (1754-1763), Britain made large gains in North America from both France and Spain and also wrestled dominance over India from France. During this period of warfare, the Dutch were able to remain neutral, whilst Britain was now allied with Prussia. The major gains in North America were largely undone by the American War of Independence (1775-1783), where the American colonists, with support from France, were able to defeat the British following a long conflict, although Britain was able to retain control over Canada. Finally, this revolutionary fervour spread to France, which later embroiled Britain in the French Revolutionary wars, and which take in the final four years of the study (1790-1794). Closer to home, the Jacobin revolt of 1745, led by the young pretender to the British throne “Bonnie Prince Charlie,” caused an associated financial panic. The Jacobin forces were able to invade from Scotland and penetrate as far as Derbyshire, before retreating and being defeated at Culloden in April 1746. Despite all of this conflict, it is of note that the London market remained open to foreign investors throughout the period of study and therefore Amsterdam residents were continually able to trade.

Figure 1 presents plots of the prices and returns to these two stocks. If we consider the price series first, it is evident that there are some fairly long swings lasting perhaps a decade at a time. The Bank of England price rose from around £90 in 1763 to almost double that value by May 1769, followed by a decade-long bear market. Another steep price rise occurred from the late 1770s, with the price peaking at around £190 in 1792, but then half this gain was lost by the end of the sample period. For the East India company, there is no real upward drift in prices. There was a rise of over 100% from the lowest value of £117 in May 1762 to around £280 by April 1769. But almost the entire
increase was wiped out in the early 1770s.

Turning now to the returns time-series in the right hand panels of the figure, the volatility clustering that is almost universally a feature of modern asset returns series is clearly evident. For both stocks, the period after the late 1770s shows a particularly high variability compared to the relatively calm markets enjoyed in the 1750s, for example. It is also clear that EIC was the considerably more volatile of the two stocks, tying in with its reputation for being involved in inherently riskier businesses than the BOE.

3.3 Hypotheses

It is generally accepted that the bulk of the relevant information flowed from London to Amsterdam (Koudijs, 2009). Consequently, one would expect the majority of price discovery to take place in London. Thus, the first null hypothesis that we consider is the following:

\[ H_0^1: \text{The London information share equals } 1/2, \]
against the alternative that it exceeds 1/2.

It is possible that price discovery may vary over time. For instance, it is quite possible that during the specific periods of war described above, relevant information from a battlefield on the European continent may reach Amsterdam before it reaches London. In this instance, we would expect Amsterdam to be the dominant market during such periods. Alternatively, institutional effects such as the imposition of the Bernard Act (or the accession of a particular Monarch) may affect the dominance of the London market during the sample period. Thus, the second null that we consider is the following:

\[ H_0^2: \text{The London information share equals } 1/2 \text{ during all selected subperiods}, \]
against the alternative that it does not equal 1/2 during all selected subperiods.

4 Results

We consider the case where (log) prices in London and Amsterdam are cointegrated with the cointegrating vector \( \beta = (1, -1)' \) imposed. Dempster et al. (2000), who also
employ a VEC model, show that each of the London stocks has a $[1 \ -1]$ cointegrating relationship with its Amsterdam counterpart and so this specification is well founded. Furthermore, to allow for deterministic seasonality in mispricing caused by the “rescounter” settlement dates of: February 15, May 15, August 15, and November 15, we include monthly dummy variables in the VEC model. This VEC model is recursively estimated over the sample (starting with the sample $t \in \{1, \ldots, 50\}$), using a uniform weighting scheme (with $\delta = 0$) and an exponential weighting scheme (with $\delta = 0.01$). In each case, lag lengths of one, two, three and four are considered.

The full sample results (except coefficients on the dummy variables) provided in Tables I and II demonstrate that past mispricings have the expected effect on future returns in London and Amsterdam. Although our parameter estimates show slight differences to those of Dempster et al. (2000), they yield broadly the same patterns. The estimated $\alpha$ parameters show that adjustment back to equilibrium was twice as quick in Amsterdam as in London for both stocks, and that for the former, almost half of the required price change to correct for a disequilibrium will take place within one period (two weeks). Specifically, when the London price is higher than the Amsterdam price (i.e., mispricing is positive), the next period returns in London and Amsterdam are significantly negative and positive, respectively. The results in this table also demonstrate that London returns tend to (Granger) cause Amsterdam prices, with the reverse generally not true.

To examine the amount of relative price discovery in each market, information shares are calculated over the sample. The results in Figure 2 show that London tends to be the dominant market with information shares slightly above $1/2$. However, it is also apparent that there is considerable variation over time. The figure also shows that there appears to be a considerable drop in the relative importance of London around 1760 when the new monarch was crowned. This may reflect the market reacting badly to the succession during a period of warfare when any instability would lead to a lack of confidence. As we have noted, an invasion in 1745 regarding an alternate claim to the throne had caused a financial panic, and the young pretender was still alive and kicking in 1760.

The results in Tables III and IV show that the London market significantly dominates for both shares. For instance, when using the exponential weighting scheme, the estimated London information shares are 56.95% and 54.20% for BOE and EIC shares, respectively.
Both of these shares are significantly above 1/2 (this is based on a paired $t$-test with Newey-West standard errors employed). Thus, it would appear that hypothesis 1 can be rejected in favour of the alternative.

The results pertaining to the determinants of the time-variation in information shares appear mixed. First, information shares do not appear to vary in a systematic fashion between peacetime and wartime (with dates adopted following Neal, 1987). For instance, when using the exponential weighting scheme, the estimated London information shares during peacetime are 55.52% and 54.27% for BOE and EIC shares, respectively, while the estimated London information shares during wartime are 59.58% and 54.08% for BOE and EIC shares, respectively. Moreover, these information shares are insignificantly different from each other over the two periods.

Information shares do appear to be determined by institutional effects. In particular, the introduction of the Bernard Act has a significant downward impact on the London information share associated with EIC shares. Thus, this act which curtailed (low cost) futures-type trading of stocks, may have been responsible for a change in the amount of relative price discovery from London to Amsterdam. Also, the accession of George III coincides with a reduction in the London information share, with the effect particularly acute for BOE shares. Indeed, when one applies a statistical procedure to determine the most likely breakpoint in the data, the Andrews-Quandt Maximum LR $F$-test selects the date 21/12/61 when using exponential weighting and BOE share data. This date is very close to the accession date of George III, which is 25/10/60, as we have previously discussed. We should also consider here a panic in London beginning in April 1761 and mentioned by Neal (1990, p. 170). Charles Mackay placed the blame for this panic on two earthquakes and the fear of a third, which had been prophesised by “a crack-brained fellow called Bell” (Mackay, 1995, p. 224). It may well be that this reduction in the information share may be unconnected to the succession of George III.

Finally, comparing Tables III and IV, it is evident that over the sample period as a whole, Amsterdam is relatively more important in price discovery terms for EIC than it is for BOE, although it declined more for BOE over time so that the difference between the two stocks became more modest. The more prominent role of Amsterdam for EIC is, perhaps, unsurprising given that the activities of BOE were focused almost exclusively
in England while EIC had activities that were more international in nature and the boats travelling between Holland and the East Indies may have assisted in increasing the preferential flow of news to Amsterdam.

5 Conclusions

This paper has employed a vector error correction model together with Hasbrouck’s information shares approach to investigate the relative price discovery roles of London and Amsterdam for the two most important stocks that were cross-listed across the two markets in the eighteenth century. The VEC model estimates show that the speed of adjustment back towards equilibrium is fast, with 20-45% of any correction occurring within one period. The only sources of information in Amsterdam were the mail packet boats, which sailed at best twice per week and sometimes with considerable delay due to a lack of wind or wind from the wrong direction. Hence, given the physical impediments to information exchange between London and Amsterdam, we find that adjustments back to equilibrium worked remarkably quickly such that any possibilities for arbitrage would have disappeared within a few weeks.

To some extent in contrast with Dempster et al. (2000), we are able to show that Amsterdam had a significant and increasing share in the price discovery of the two markets over time, although the role of London was still greater throughout the sample period. Following Neal’s (1987) suggestion, we split the sample in various ways in order to investigate the impact that wars, changes in regulatory regime (viz. the Barnard Act), and a change of English monarch, had on the relative importance of the two centres in the price discovery process, finding that only a change of king in 1760 made any statistically significant difference.

Turning now to possible avenues for future research, it would be of interest to further investigate the period around 1760-1761 to determine the likely reason for the reduction at that time in the London information share. In addition, as we have noted, the study is arbitrarily fixed to the period of data collection by van Dillon (1931). A wider collection

\footnote{See Koudijs (2009) for a detailed discussion of flows between London and Amsterdam and how volatility is affected by the arrival of news.}
of data would allow a longer and more detailed study. In should be possible to collect data from Amsterdam to match that collected from the London sources, rather than relying on two-weekly data observations. As a much richer data source exists, it is a pity that considerably more data has yet to be collected to facilitate a more in-depth study.
References


significant coefficients or test statistics are denoted by ( ) and p-values associated with the Granger causality tests are given in square brackets. Statistically that London (Amsterdam) returns do not Granger cause Amsterdam (London) returns. Standard errors are given superscript, and coefficients on past Amsterdam returns have an \( A \) column, while the Amsterdam results are given in the \( L \) column. Coefficients on past London returns have an \( L \) superscript, and coefficients on past Amsterdam returns have an \( A \) superscript. Also included are the adjusted \( R^2 \) statistics, the Akaike information criterion (AIC) value, and the test statistic associated with the null hypothesis that London (Amsterdam) returns do not Granger cause Amsterdam (London) returns. Standard errors are given in parenthesis and p-values associated with the Granger causality tests are given in square brackets. Statistically significant coefficients or test statistics are denoted by ** (1% significance), and * (5% significance).

Table I: Full sample parameter estimates for the Bank of England

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VEC(1)</th>
<th>VEC(2)</th>
<th>VEC(3)</th>
<th>VEC(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( L )</td>
<td>( A )</td>
<td>( L )</td>
<td>( A )</td>
</tr>
<tr>
<td>( \Gamma_L^1 )</td>
<td>( -0.058 )</td>
<td>( 0.087^* )</td>
<td>( -0.070 )</td>
<td>( 0.157^{**} )</td>
</tr>
<tr>
<td></td>
<td>( (0.038) )</td>
<td>( (0.037) )</td>
<td>( (0.046) )</td>
<td>( (0.044) )</td>
</tr>
<tr>
<td>( \Gamma_L^2 )</td>
<td>( 0.009 )</td>
<td>( 0.103^{**} )</td>
<td>( 0.003 )</td>
<td>( 0.164^{**} )</td>
</tr>
<tr>
<td></td>
<td>( (0.037) )</td>
<td>( (0.036) )</td>
<td>( (0.045) )</td>
<td>( (0.044) )</td>
</tr>
<tr>
<td>( \Gamma_L^5 )</td>
<td>( -0.016 )</td>
<td>( 0.084^* )</td>
<td>( 0.015 )</td>
<td>( 0.157^{**} )</td>
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<td>( (0.037) )</td>
<td>( (0.046) )</td>
<td>( (0.044) )</td>
</tr>
<tr>
<td>( \Gamma_A^2 )</td>
<td>( 0.077^* )</td>
<td>( -0.062 )</td>
<td>( 0.087^* )</td>
<td>( -0.131^{**} )</td>
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<td>( (0.035) )</td>
<td>( (0.034) )</td>
<td>( (0.043) )</td>
<td>( (0.041) )</td>
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<tr>
<td>( \Gamma_A^2 )</td>
<td>( 0.051 )</td>
<td>( -0.079^* )</td>
<td>( 0.064 )</td>
<td>( -0.140^{**} )</td>
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<td>( (0.034) )</td>
<td>( (0.033) )</td>
<td>( (0.043) )</td>
<td>( (0.042) )</td>
</tr>
<tr>
<td>( \alpha )</td>
<td>( -0.191^{**} )</td>
<td>( 0.446^{**} )</td>
<td>( -0.184^{**} )</td>
<td>( 0.383^{**} )</td>
</tr>
<tr>
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<td>( (0.040) )</td>
<td>( (0.039) )</td>
<td>( (0.046) )</td>
<td>( (0.045) )</td>
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<tr>
<td>( \bar{R}^2 )</td>
<td>7.366%</td>
<td>5.586%</td>
<td>7.573%</td>
<td>18.512%</td>
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<tr>
<td>AIC</td>
<td>( -5.496 )</td>
<td>( -5.562 )</td>
<td>( -5.497 )</td>
<td>( -5.564 )</td>
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<tr>
<td></td>
<td>[0.029]</td>
<td>[0.018]</td>
<td>[0.111]</td>
<td>[0.008]</td>
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</table>
significant coefficients or test statistics are denoted by in parenthesis and p-values associated with the Granger causality tests are given in square brackets. Statistically that London (Amsterdam) returns do not Granger cause Amsterdam (London) returns. Standard errors are given statistics, the Akaike information criterion (AIC) value, and the test statistic associated with the null hypothesis that London (Amsterdam) returns do not Granger cause Amsterdam (London) returns. Standard errors are given in parenthesis and p-values associated with the Granger causality tests are given in square brackets. Statistically significant coefficients or test statistics are denoted by ** (1% significance), and * (5% significance).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>VEC(1)</th>
<th>VEC(2)</th>
<th>VEC(3)</th>
<th>VEC(4)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>(L)</td>
<td>(A)</td>
<td>(L)</td>
<td>(A)</td>
</tr>
<tr>
<td>(\Gamma_1^L)</td>
<td>0.038</td>
<td>0.184**</td>
<td>-0.005</td>
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<td></td>
<td>(0.040)</td>
<td>(0.036)</td>
<td>(0.049)</td>
<td>(0.045)</td>
</tr>
<tr>
<td>(\Gamma_2^L)</td>
<td>-0.038</td>
<td>0.097**</td>
<td>-0.051</td>
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<td></td>
<td>(0.040)</td>
<td>(0.037)</td>
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<td>(0.045)</td>
</tr>
<tr>
<td>(\Gamma_3^L)</td>
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<td>0.076*</td>
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<td>(0.045)</td>
</tr>
<tr>
<td>(\Gamma_4^L)</td>
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<td>0.098**</td>
<td>0.036</td>
<td>0.098**</td>
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<tr>
<td>(\Gamma_1^A)</td>
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<td>-0.122**</td>
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<td>(0.044)</td>
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<tr>
<td>(\Gamma_2^A)</td>
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<td>(0.037)</td>
<td>(0.034)</td>
<td>(0.049)</td>
<td>(0.044)</td>
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<tr>
<td>(\Gamma_3^A)</td>
<td>0.055</td>
<td>-0.005</td>
<td>0.029</td>
<td>-0.073</td>
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<td></td>
<td>(0.038)</td>
<td>(0.034)</td>
<td>(0.050)</td>
<td>(0.045)</td>
</tr>
<tr>
<td>(\Gamma_4^A)</td>
<td>-0.014</td>
<td>-0.034</td>
<td>-0.014</td>
<td>-0.034</td>
</tr>
<tr>
<td>(\alpha)</td>
<td>-0.221**</td>
<td>0.452**</td>
<td>-0.184**</td>
<td>0.396**</td>
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<tr>
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<td>(0.046)</td>
<td>(0.041)</td>
<td>(0.052)</td>
<td>(0.047)</td>
</tr>
<tr>
<td>(R^2)</td>
<td>2.637%</td>
<td>19.498%</td>
<td>3.436%</td>
<td>19.814%</td>
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<td>Causality Test</td>
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<td>11.813**</td>
<td>30.847**</td>
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<td>[0.818]</td>
<td>[0.000]</td>
<td>[0.003]</td>
<td>[0.000]</td>
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### Table III: London Information Shares for Bank of England

This table provides the estimated London information shares based on time-varying VEC models with optimal lag structure based on the AIC values observed at each point in the recursive sample. These information shares are provided over various sub-samples. The null hypothesis is that the London information share equals 1/2, and is tested using t-tests based on Newey-West standard errors. The breakpoints are pre-determined, or statistically-determined via use of a Andrews-Quandt maximum LR F-test for parameter stability at an unknown breakpoint.

<table>
<thead>
<tr>
<th>Sample Period</th>
<th>$\delta = 0$</th>
<th>$\delta &gt; 0$</th>
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</thead>
<tbody>
<tr>
<td>Peace 1 (09/08/23 - 19/10/39)</td>
<td>65.400**</td>
<td>64.463**</td>
</tr>
<tr>
<td>Peace 2 (11/11/48 - 14/07/56)</td>
<td>62.668**</td>
<td>60.388**</td>
</tr>
<tr>
<td>Peace 3 (18/02/63 - 04/03/78)</td>
<td>56.504**</td>
<td>49.065</td>
</tr>
<tr>
<td>Peace 4 (06/12/82 - 22/09/90)</td>
<td>53.926**</td>
<td>49.585</td>
</tr>
<tr>
<td>War 1 (21/10/39 - 23/10/48)</td>
<td>62.721**</td>
<td>56.966**</td>
</tr>
<tr>
<td>War 2 (04/08/56 - 05/02/65)</td>
<td>66.257**</td>
<td>71.200**</td>
</tr>
<tr>
<td>War 3 (02/03/78 - 20/11/82)</td>
<td>56.394**</td>
<td>53.241**</td>
</tr>
<tr>
<td>War 4 (08/10/90 - 19/12/94)</td>
<td>53.608**</td>
<td>53.232**</td>
</tr>
<tr>
<td>All Peace</td>
<td>59.625**</td>
<td>55.517*</td>
</tr>
<tr>
<td>All War</td>
<td>61.085**</td>
<td>59.583**</td>
</tr>
<tr>
<td>Difference</td>
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<td>-4.066</td>
</tr>
<tr>
<td>Pre Barnard Act (09/08/23-20/12/37)</td>
<td>65.764**</td>
<td>64.931**</td>
</tr>
<tr>
<td>Post Barnard Act (01/01/38-19/12/94)</td>
<td>59.129**</td>
<td>55.519*</td>
</tr>
<tr>
<td>Difference</td>
<td>6.635</td>
<td>9.413</td>
</tr>
<tr>
<td>George II (09/08/23-13/10/60)</td>
<td>64.132**</td>
<td>63.077**</td>
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<tr>
<td>George III (14/11/60-19/12/94)</td>
<td>56.236**</td>
<td>50.962</td>
</tr>
<tr>
<td>Difference</td>
<td>7.895</td>
<td>12.115**</td>
</tr>
<tr>
<td>Pre Max. LR Breakpoint</td>
<td>64.344**</td>
<td>63.434**</td>
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<tr>
<td>Post Max. LR Breakpoint</td>
<td>55.552**</td>
<td>50.178</td>
</tr>
<tr>
<td>Difference</td>
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<td>13.256**</td>
</tr>
<tr>
<td>All</td>
<td>60.141**</td>
<td>56.954**</td>
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<td>Andrews-Quandt Maximum LR F-statistic</td>
<td>6828.355**</td>
<td>1595.055**</td>
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<tr>
<td>Andrews-Quandt Maximum LR Breakpoint</td>
<td>06/09/62</td>
<td>21/12/61</td>
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</table>
Table IV: London Information Shares for East India Company

This table provides the estimated London information shares based on time-varying VEC models with optimal lag structure based on the AIC values observed at each point in the recursive sample. These information shares are provided over various sub-samples. The null hypothesis is that the London information share equals 1/2, and is tested using t-tests based on Newey-West standard errors. The breakpoints are pre-determined, or statistically-determined via use of a Andrews-Quandt maximum LR F-test for parameter stability at an unknown breakpoint.

<table>
<thead>
<tr>
<th>Sample Period</th>
<th>$\delta = 0$</th>
<th>$\delta &gt; 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peace 1 (09/08/23 - 19/10/39)</td>
<td>57.607**</td>
<td>58.746**</td>
</tr>
<tr>
<td>Peace 2 (11/11/48 - 14/07/56)</td>
<td>54.979**</td>
<td>50.814</td>
</tr>
<tr>
<td>Peace 3 (18/02/63 - 04/03/78)</td>
<td>52.757**</td>
<td>53.344</td>
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<tr>
<td>Peace 4 (06/12/82 - 22/09/90)</td>
<td>53.320**</td>
<td>52.723</td>
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<tr>
<td>War 1 (21/10/39 - 23/10/48)</td>
<td>56.478**</td>
<td>51.292</td>
</tr>
<tr>
<td>War 2 (04/08/56 - 05/02/63)</td>
<td>57.126**</td>
<td>61.102**</td>
</tr>
<tr>
<td>War 3 (02/03/78 - 20/11/82)</td>
<td>53.053**</td>
<td>52.904*</td>
</tr>
<tr>
<td>War 4 (08/10/90 - 19/12/94)</td>
<td>53.015**</td>
<td>49.555</td>
</tr>
<tr>
<td>All Peace</td>
<td>54.618**</td>
<td>54.270**</td>
</tr>
<tr>
<td>All War</td>
<td>55.451**</td>
<td>54.077**</td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td>−0.833</td>
<td>0.193</td>
</tr>
<tr>
<td>Pre Barnard Act (09/08/23-20/12/37)</td>
<td>57.341**</td>
<td>58.816**</td>
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<tr>
<td>Post Barnard Act (01/01/38-19/12/94)</td>
<td>54.475**</td>
<td>53.372**</td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td>2.866</td>
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</tr>
<tr>
<td>George II (09/08/23-13/10/60)</td>
<td>56.634**</td>
<td>55.523**</td>
</tr>
<tr>
<td>George III (14/11/60-19/12/94)</td>
<td>53.227**</td>
<td>52.909*</td>
</tr>
<tr>
<td><strong>Difference</strong></td>
<td>3.407**</td>
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<tr>
<td>Pre Max. LR Breakpoint</td>
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<tr>
<td>Post Max. LR Breakpoint</td>
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</tr>
<tr>
<td><strong>Difference</strong></td>
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</tr>
<tr>
<td>All</td>
<td>54.912**</td>
<td>54.202**</td>
</tr>
</tbody>
</table>

Andrews-Quandt Maximum LR F-statistic 2601.502** 221.7740**
Andrews-Quandt Maximum LR Breakpoint 06/09/62 31/08/39
Figure 1: Cross-listed prices and returns

This figure plots the prices and log returns associated with Bank and England (BOE) and East India Company (EIC) shares over the sample period, 09/08/1723 to 19/12/1794.
Figure 2: Time-varying London information shares

This figure plots the estimated London information shares associated with Bank and England (BOE) and East India Company (EIC) shares. These shares are calculated using time-varying VEC models with optimal lag structure based on the AIC values observed at each point in the recursive sample.