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THE BOATS THAT DID NOT SAIL: ASSET PRICE VOLATILITY AND MARKET EFFICIENCY IN A NATURAL EXPERIMENT

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Working Paper 18831
http://www.nber.org/papers/w18831

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
February 2013

This paper is based on the first chapter of my dissertation. I thank Hans-Joachim Voth (my advisor) and Fernando Broner and Jaume Ventura (committee members) for their advice and support. I thank Karine van der Beek, Harry Garretsen, Benjamin Golez, Jakub Jurek, Floor Koudijs, Larry Neal, Andrej Ukhov, Nico Voigtländer, Jan de Vries and Jan Luiten van Zanden and seminar participants at Cambridge, CPB, Evanston (EHA meetings), Geneva (EHES meetings), Princeton, Nottingham (EHS meetings), NYU Stern, UC Davis, UC Berkeley, Utrecht University, and Tilburg University for their feedback. Many thanks to Daphne Acoca, Michelle Lee, Sophia Paliza and Hannah Rusk for excellent research assistance. Any errors are my own. This project was financed by the Spanish Ministry of Education and Stanford GSB. The views expressed herein are those of the author and do not necessarily reflect the views of the National Bureau of Economic Research.

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February 2013
JEL No. G14,N2

ABSTRACT

Financial markets are thought to be inefficient when they move too much relative to the arrival of information. How big is this inefficiency? In today's markets, this is difficult to determine because the arrival of information is hard to identify. In this paper, I present a natural experiment from history in which the flow of information was regularly interrupted for exogenous reasons. This allows me to study volatility in the absence of news, and to identify the degree of inefficiency. During the 18th century a number of English securities were traded on the Amsterdam exchange. Relevant information from England reached Amsterdam on mail boats. I reconstruct their arrival dates. When no mail boats arrived, virtually no other relevant information reached the Amsterdam market. I measure price volatility during periods with and without news. Even in the absence of new information, security prices moved significantly. Between 50 and 75% of overall volatility did not reflect the arrival of news. A significant fraction of this residual is driven by the incorporation of private information into prices. Once this is taken into account, 20 to 50% of the overall return variance is unexplained by information. This suggests that the Amsterdam market moved more than can be explained by the arrival of news but that the majority of price movements was still the result of efficient price discovery.

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An online appendix is available at:
http://www.nber.org/data-appendix/w18831

Financial markets are thought to be efficient when they aggregate all available information (Fama 1970). They are inefficient when they either do not reflect all available news or when they move too much relative to arriving information. Market inefficiencies have potentially large welfare costs. They hamper the efficient allocation of resources in an economy, restrict the participation of risk averse investors and limit risk sharing. A large body of literature suggests that markets are inefficient and that asset prices fluctuate more than can be explained by news (e.g. Schiller 1981; Schwert 1981, 1989; Roll 1984, 1988; French and Roll 1986; Cutler et al. 1989[1]).

Assessing market efficiency is not straightforward. In modern markets information arrives continuously. It is virtually impossible to study how much markets would have moved if no news had arrived. Relating asset price fluctuations to the intensity of news arrival is also difficult because the latter is hard to measure. It is often unclear when certain news is observed and whether this information is relevant.[2] In addition, a large fraction of information might be private in nature, arriving in the market in the form of informed trades.

Using a unique historical case, this paper analyzes a market's price process in the absence of information arrival. I examine the market for English securities in Amsterdam in the 18th century. These were mainly traded in London, but there was active trading in Amsterdam as well.[3] For the specific periods that I study (1771-1777 and 1783-1787) virtually all relevant information originated in the British capital. Crucially, news flows from London to Amsterdam were interrupted for exogenous reasons. Relevant information reached the continent via sailing boats. Between London and Amsterdam there was an official packet boat service, which sailed twice a week. Adverse weather could delay boats substantially. As a result, Amsterdam was often starved of new information from England for days in a row. We can therefore observe how high volatility was in the absence of news.[4]

[1] See also Fair (2002).

[2] We often do not know that relevant information has arrived until the market actually moves.

[3] Amsterdam was not just a small satellite market. Dutch holdings of English securities during the 1770s and 1780s fluctuated between 20 and 30% of the total (Bowen 1989; Wright 1999).

[4] This specific approach is only feasible in an historical setting with serious constraints on communication technology. Garbade and Silber (1978) show that the introduction of the telegraph in the middle of the 19th century already led to highly integrated financial markets (see also Sylla et al. 2006 and Hoag 2006).

I show that price changes without news were considerable - between 50 and 75% of the overall return variance cannot be explained by the arrival of public information. Trading in Amsterdam continued during periods without news and price changes reflected actual transactions (see appendix C for details).

The volatility in the absence of news does not only capture inefficiencies; it also reflects the incorporation of private information into prices. I estimate a structural model to capture this dimension. The estimates indicate how much volatility remains after both public and private information are taken into account. The analysis relies on the covariance of price changes in London and Amsterdam (De Jong and Schotman 2010). The intuition is as follows. The variance of returns in both London and Amsterdam was driven by the incorporation of new public and private information. In addition, if markets were inefficient, other factors referred to as 'noise' would also affect prices. I assume that noise shocks in the two markets were uncorrelated. Under this assumption the covariance of returns in London and Amsterdam should only reflect the incorporation of information.[5] The proportion of price changes that cannot be explained by the response to information captures noise.[6]

Once the impact of public and private information has been taken into account, 20 to 50 % of the return variance can be attributed to noise. Overall, these results imply that prices in Amsterdam moved more than can be explained by new information. At the same time, the size of the inefficiency is relatively small: at least half of the return variance can be attributed to the arrival to news.

Several unique features of the historical setting allow for a clean identification of periods without news. First of all, for all practical purposes there was only one source of information:

[5] The impact of public information is measured as the covariance of Amsterdam returns with price changes in London that were observed by the market in Amsterdam after arrival of the packet boat. The impact of private information is measured as the covariance with contemporaneous price changes in London that had not yet been reported by the mail boats. The reason is that, as the same private signal is revealed in both markets, prices move in the same direction.

[6] It is possible that London prices contained noise and that this affected prices in Amsterdam. This does not affect the volatility in the absence of news (the focus of this study), but it would inflate the variance of returns with news. In addition, it would increase the (perceived) importance of public news. Arguably, this is not a crucial issue. First of all, markets are efficient when they respond to all available information. If that information is the London price, then it is part of market efficiency for the Amsterdam market to respond to that price. Secondly, the empirical results suggest that the response in Amsterdam to London noise was quantitatively unimportant. London noise reverted relatively quickly and the Amsterdam market did not respond to these temporary price changes.

England. The stocks studied in this paper were all English and it is natural that most relevant information originated in England. Moreover, the sample periods are selected to exclude any major events on the European continent that may have affected prices. Secondly, there was only one important channel through which information could reach Amsterdam: the packet boat. If the official packet boat was delayed due to adverse winds, other sailing boats had trouble crossing the North Sea as well. In addition, there were no alternative means of transport from London to Amsterdam except sailing boats. Carrier pigeons were not used until after 1800 (Levi 1977). Steam boats and the invention of the telegraph were even further into the future. Thirdly, the flow of information was exogenous. The packet boat schedule was fixed and major political or economic events did not lead to more or faster crossings of packet boats. Finally, Amsterdam prices immediately reflected the arrival of public news. There is virtually no return continuation or momentum.

Figure 1 illustrates these points with a concrete example of price developments in London and Amsterdam. On November 18, 1783 English prime-minister Fox declared that the British East India Company's (EIC) finances were in a "deplorable state" (London Chronicle, November 18, 1783; Sutherland 1952, p. 375). The company's stock price in London fell dramatically from 136 to 120. The vertical/diagonal black lines indicate how and when the packet boats transmitted this news to Amsterdam. In the days following the drop on the English exchange, weather conditions were unfavorable and the packet boat could not cross the North Sea. Meanwhile, the EIC's stock price in Amsterdam remained virtually unchanged and did not yet reflect the news from England. Apparently, no other boats managed to get this major news across. After wind conditions changed, a packet boat reached the Dutch Republic on November 28, ten days after Fox gave his speech. Prices immediately fell sharply.

[Figure 1 about here]

Whether markets move too much relative to the arrival of new information is the subject of a large literature. Several studies document that prices move significantly in the absence of relevant news (Schiller 1981; Schwert 1981, 1989; Roll 1988; Cutler et al. 1989). News may explain 2% or less of overall daily stock price fluctuations (Berry and Howe 1994; Mitchell and Mulherin 1994; Andersen et al. 2000; Kalev et al. 2004). This implies that markets are inefficient, but measurement issues are formidable.[7] Other contributions analyse securities for which public information is easier to observe, such as weather-sensitive assets (Roll 1984; Boudoukh et al. 2007; Fleming et al. 2006). Related to these studies is Yermack (2012) who shows that stocks are less volatile when CEOs are on vacation and news announcements are delayed. These studies find an important role for public information, but a large fraction of volatility remains unexplained.[8] Although these studies may miss important alternative sources of information (such as demand shocks or private information), the hypothesis that markets move too much relative to information cannot be rejected.

A second strand in the literature looks at periods during which information arrives as usual but markets are closed (French and Roll 1986; Barclay et al. 1990; Ito and Lin 1992; Ito et al. 1998). These studies find that the return variance is surprisingly low when trade is restricted.[9] These findings also point to market inefficiency, but the timing of market closures is not always exogenous, and restricting trading may affect the flow of news.[10] This makes separating the impact of news from the trading process difficult. Higher volatility in the presence of trade may also be due to the revelation of private information through the trading process, but is not straightforward to test for this (compare Andersen et al. 2001).[11]

[7]The arrival of public news has more explanatory power for the risk free interest rate (Ederington and Lee 1993; Fleming and Remolona 1999; Balduzzi et al. 2001), where it explains around 25% overall daily volatility (Bollerslev et al. 2000). In a closely related paper, Elmendorf et al. (1996) confirm this for weekly government bond returns in the UK between 1900 and 1920. Similar to the interest rate, public news seems to drive an important fraction (around 15%) of daily exchange rate fluctuations (DeGennaro and Schrieves 1997; Andersen and Bollerslev 1998; Melvin and Yin 2000; Evans and Lyons 2008; Ito and Hashimoto 2008).

More recent contributions use textual analysis to identify the impact of different types of news (Antweiler and Frank 2004; Demers and Vega 2006; Tetlock 2007; Tetlock et al. 2008; Davis et al. 2012).

[8]For example, Boudoukh et al. (2007) find that during the winter months up to a third of the variation in orange juice prices can be explained by temperature. When all months of the year are taken into account, this falls to about one sixth.

[9]For example, French and Roll (1986) find that the return variance on days without trade was only 14.5% of the return variance on days with trade.

[10]For example, Mitchell and Mulherin (1994) document that there is a reduction in news items around market holidays. One interpretation is that more news is generated when the markets are open and there is an immediate demand for it. Alternatively, companies may have an incentive to release information when markets are open.

[11]This paper complements the literature on the impact of private information (Hasbrouck 1991; Easley et al 1997 and related studies) and more specifically studies that jointly estimate the impact of private and public information (Madhavan et al. 1997; Evans and Lyons 2002; Vega 2006; Pasquariella and Vega 2007 and Tetlock 2010a). In a separate paper (Koudijs 2012) I study the incorporation of private information in further detail. I show that the patterns in the data are consistent with strategic behavior on part of the

Third, this paper is related to studies on cross-listings, specifically to contributions that look at how trading in a foreign market (usually the US) is affected when home markets are open or closed. Security prices are more volatile during the hours the home market is open (Harvey and Huang 1991; Forster and George 1995; see also Werner and Kleidon 1996). Nevertheless, a large share of price discovery takes place outside these hours. In addition, return patterns of domestic and foreign securities in New York are strikingly similar over the US trading day (Chan et al. 1996, see also Koopman et al. 2007). This might demonstrate that factors other than information are important contributors to volatility, but it could also point to the importance of news about the foreign (US) economy for cross-listed stocks.

Finally, this paper builds on other studies of the London and Amsterdam securities markets in the 18th century. Neal (1987, 1990) documents that the Amsterdam and London markets were well integrated (see also Dempster et al. 2000). He also shows that markets were efficient in the sense that return predictability was virtually absent. Harrison (1998) studies the time series properties of returns in London and Amsterdam and argues that these were very similar to those of 20th century markets.[12]

Relative to the existing literature, this paper makes several contributions. I improve on the existing historical research by collecting detailed information about the sailing of packet boats, by drawing on information about weather conditions on the North Sea in the 18th century, and by using this to analyse the efficiency of markets.[13] The historical setting of this paper offers distinct advantages. Instead of analysing the effect of market closures, or attempting to identify and measure the importance of information, I focus on interruptions to news arrival. These were the result of varying weather conditions and a fixed sailing schedule, and can be considered truly exogenous. Second, modern-day studies that look at foreign stocks listed in the US face difficulties of interpretation because US markets are central to world economic conditions. In contrast, developments in the Netherlands were much less important for global conditions (or the UK) in the 1770s and 1780s. Finally,

privately informed agents, confirming the predictions from Kyle (1985) and related models.

[12] This paper is also related to studies that use other historical settings to study the sources of asset price volatility (see inter alia Elmendorf et al. 1996; Silber 2001; Brown et al. 2008).

[13] In addition, the price data collected for the Amsterdam market have a higher frequency (3 observations a week instead of 2 observations a month) than the existing studies.

assessing the impact of private information is more straightforward in my historical setting. In combination, the trading in dual-listed English securities in the 18$^{\text{th}}$ century provides a unique historical experiment to investigate the efficiency of asset pricing and the impact of news on volatility.

The remainder of the paper is organized as follows. Section 1 discusses the historical context of this paper in more detail. I elaborate on how news from England reached Amsterdam and how I can reconstruct these information flows. Section 2 presents the baseline estimates and shows that the variance of returns was considerable in the absence of news. Before turning to the structural model that takes the impact of private information into account (which will be discussed in section 6), I first discuss a number of key features of the historical setup. Section 3 provides more information about news flows between London and Amsterdam. Section 4 tests whether news was immediately incorporated into prices. Section 5 investigates the possible impact of London noise on Amsterdam prices. Section 7 concludes. Additional information and results are presented in appendices A through E which are made available separately.

1 Historical background and data

1.1 Stocks and sample period

I examine all English securities cross-listed in Amsterdam for which frequent price data is available. See Appendix A for the data sources. This includes three stocks and two government bonds: the East India Company (EIC), the Bank of England (BoE) and the South Sea Company (SSC) and the 3 and 4% annuities. The three companies were concerned with a number of activities. The British East India Company (EIC) was a trading company that held large possessions in what is today's India. The company's prospects were determined by conditions in India and political developments in England (Sutherland 1952). The Bank of England (BoE) and the South Sea Company (SSC) both operated to help finance the British government debt.[14] The BoE also provided large scale credit to the EIC and it discounted commercial bills (Clapham 1944).

The archival records indicate that an active trade in English securities existed on the Amsterdam exchange (Van Dillen 1931; Van Nierop 1931; Wilson 1941). Although volume data are unavailable for the period, some inferences can be made about the size of the Amsterdam market for British stocks. Bowen (1989) and Wright (1999) show that during the 1770s around one third of the shares in the British companies were in the hands of Dutch investors. During the 1780s this fell to around a fifth.[15] This is only a rough indicator of the Amsterdam market's importance since British investors could also choose to trade in the Netherlands and Dutch investors could likewise place their orders in London (Van Nierop 1931; Wilson 1941). Trade in English securities was not confined to the spot market. The Amsterdam market also featured an active trade in futures and options (Van Dillen 1931). In addition, the market for repos on the collateral of English securities was well developed (Wilson 1941; Koudijs and Voth 2012).

The sample periods are September 1771 – December 1777 and September 1783 – March 1787. The identification strategy of this paper rests on the assumption that most relevant information about the English stocks was generated in England. For the 18th century as a whole it is likely that news could originate elsewhere than England (Dempster et al. 2000). The period was filled with European continental wars or the threat of a war breaking out, and England was involved in nearly all of them (Neal 1990). In addition, during the 18th century Amsterdam was still the financial capital of the world. Financial crises like the one in 1763 were centered on the city (De Jong-Keesing 1939; Schnabel and Shin 2004). It is obvious that such developments could have been of key importance for the pricing of the English stocks. That is why the analysis is restricted to two specific subperiods (1771-1777 and 1783-1787) for which I expect that most news had its origins in England. Both sample periods were characterized by peace on the European continent and the absence of severe

[14] The SSC originally had the purpose to transport slaves from Africa to the Spanish American colonies. These activities never really materialized and the company functioned predominantly as an investment vehicle in British government debt (Neal 1990).

[15] For the SSC these fractions are slightly higher. For the 3% Annuities these fractions are slightly lower.

financial crises.[16] In section 3 I perform a number of tests that confirm that for this period virtually all relevant news had its origins in England.

1.2 The flow of information between London and Amsterdam

1.2.1 Official news flows

How exactly did news from England reach Amsterdam? Since 1660, England and the Dutch Republic had been connected through a system of sailing ships, at the time referred to as packet boats, that were specifically designed for the trajectory. The system had been set up to ensure a swift and regular information flow between the two countries. The system was organized between Harwich and Hellevoetsluys, an important harbor close to Rotterdam (see figure 2). Since Amsterdam did not have a direct connection with the North Sea (boats had to sail past the isle of Texel), this was the fastest way information from London could reach Amsterdam (Hemmeon 1912; Stitt Dibden 1965; Ten Brink 1969; OSA 2599). For the analysis of this paper, I reconstruct the arrival dates of the packet boats. See Appendix A for more details.

[Figure 2 about here]

The packet boats were scheduled to leave on fixed days: Wednesday and Saturday. The median sailing time was 2 days (including the day of departure). It took additional time to transport the news over land. Roads were particularly bad during the period and rivers had to be crossed by ferry. Even though the news was transported on horseback, this still took considerable time, adding two days, making a total of 4 days (including the day of departure).[17]

The sailing ships often encountered adverse winds and as a result the news could be significantly delayed for days, sometimes even weeks. Around a third of the North Sea crossings from England to Holland were delayed. The longest delay I encountered was 17

[16] See appendix A for more details. The sample selection is also partly driven by data limitations

[17] In London news would be collected by the end of the day on Tuesday or Friday (day of departure: day 1). This was transported to Harwich in the early morning, from where a mail packet boat would set sail in the afternoon (day 2). The boat would usually arrive in Hellevoetsluys on the next day (day 3). After the news had arrived it was quickly sent to Amsterdam where it usually arrived the day after (day 4).

days. As a result there was considerable variation in the time between the arrival of boats. During these periods of bad weather no news was transmitted across the North Sea. The *Tatler*, an English newspaper of the time, described that there could be a news blackout in London "when a West wind blows for a fortnight, keeping news on the other side of the Channel" (Dale 2004, p. 17). The same was true for Amsterdam when the wind was blowing from the East.

The packet boat system was the main source of English information for investors in Amsterdam. The Dutch newspapers of the time all relied on the packet boat service to get news from England. During the sample period, all articles in the *Amsterdamsche Courant* and the *Rotterdamsche Courant* with new information from London can be retraced to the arrival of a specific packet boat, except for a number of exceptions I discuss below. Furthermore, evidence points out that the transmission of private letters also relied on the packet boat system. This is borne out by the English correspondence from Hope & Co during the sample period. Hope was one of the biggest Dutch banking houses of the period, very active on the stock market and with strong connections in England (for example acting as an agent for English insiders, Koudijs 2012). All correspondence with their English counterparties took place through the packet boat system.[18] This suggests that important individuals received important news at the same time as the general public. Even Nathan Rothschild, who famously was the first in London to receive news about the outcome of the Battle of Waterloo in 1815, only received this information a few hours before the general public (Dale 2004, p. 17).

At times, during periods of particularly bad weather, the English news would arrive in Amsterdam through the harbor of Ostend in today's Belgium, which had a regular packet boat service with Dover in England (see figure 2). During such episodes it was impossible for the packets to sail between Harwich and Hellevoetsluys but other packet boats seem

[18] Most English letters in the Hope archive mention both the date a letter was written in London and the date it was received and opened in Amsterdam. I found 112 letters that Hope received from London. Of these 112, 99 were dated on mail days and were specifically written right before the next mail packet would leave. For 83 out of these 112 letters, I could identify on what day Hope received and opened these letters. Out of these 83 letters, 73 were received on days the mail packet arrived in Amsterdam. Five letters were opened one day late, after the news had arrived in the evening of the previous day. The final five letters were for some reason only opened a number of days later (Hope & Co, SAA 735: 78,79, 115 and 1510).

to have managed to get across to Ostend. With a total of nine times this happened only infrequently during the sample periods. These episodes were meticulously reported by the Dutch newspapers and I account for them in the empirical analysis.[19]

What was the precise content of the news transmitted from London to Amsterdam? Amsterdam investors would receive the full public information set available to English investors. Each packet boat brought in papers and other newsletters with information about recent developments in London including the most recent security prices. Finally the packet boats brought in private letters from London correspondents filled with political and economic news and updates about stock market conditions.[20].

Private letters were also used to transmit private information. Especially for the EIC there is ample evidence that London insiders such as company directors or politicians held significant private information (Sutherland 1952, 206-208, 228; Van Nierop 1931, p. 68; Koudijs 2012). Insider trading would take place in both the London and Amsterdam markets. For example, during the 1760's a group of parliamentarians, amongst whom Lord Shelburne, a later Prime-Minister, and Lord Verney, member of the Privy Council, regularly engaged in insider trading in EIC stock. The Dutch banker Gerrit Blaauw traded for their account in the Amsterdam market (Sutherland 1952, pp. 206-8). In 1773 Thomas Walpole, another English parliamentarian (and nephew of a former Prime-Minister), teamed up with the Dutch banker Hope & Co. to trade on his private information in Amsterdam.

1.2.2 Possible alternative sources of information

The packet boats were of course not the only ships that sailed between London and Amsterdam. Freightships coming from England would frequently dock in the Amsterdam harbor. However in terms of keeping up with current affairs these ships were always behind the packet boats (*Rotterdamsche* and *Amsterdamsche Courant*, passim). They were slower than

[19] I did not find a single reference to English letters received over Calais. Apparently, from a Dutch perspective, the Ostend connection always beat the Calais one.

[20] Wilson (1941, pp. 74-75); Van Nierop (1931). These private letters could also contain buy or sell orders. See for example Hope & Co, SAA 735: 78,79, 115 and 1510. This is a potential complication that I adress in sections 3 and 6.

the packet boats and they had to sail via the isle of Texel which would take additional time (see figure 2).

Although the packet boat service seems to have been the most important source of information for Dutch investors, the flow of news through alternative channels can never be completely ruled out. For starters, it is possible that market participants used carrier pigeons to get information from London. This is only hypothetical. Even though the use of carrier pigeons can be retraced to antiquity, the historical record suggests that they were only used after 1800 in Western Europe (Levi 1977). If they did play a role in the 1770s and 1780s, they could only have been used in the summer months. The birds did not cope well with winter weather (Dickens 1850; Ten Brink 1957). We would therefore expect to see different volatility patterns in Amsterdam in the winter months when compared to the rest of the year. This is not the case. See Appendix D for a more thorough discussion and empirical evidence.

A more important worry seems to be the use of private ships. It is possible that investors set up private initiatives to get information from London.[21] Again, the private correspondence from Hope & Co. does not suggest that private boats were used. The costs of hiring private ships may have outweighed the benefits. Of course, this does not completely disprove this possibility. One way to approach this issue is to take weather conditions seriously into account. It seems reasonable to assume that if the official packet boats could not sail because of adverse weather conditions, it would have been difficult for other boats to cross the North Sea as well.[22] This is most clearly illustrated by the example of figure 1. The price fall in EIC stock after PM Fox's speech is the largest in my sample. Nevertheless, this information was not transmitted to Amsterdam until the packet boats were able to cross the North Sea. In section 3 I use this logic to perform a number of robustness checks. I show that return volatility in Amsterdam on days without news was just as high during adverse

[21] For example, there are rumors from the South Sea bubble in 1720 that Dutch investors chartered their own fishing ships to get the most recent information from London (Smith 1919; Jansen 1946). Jansen however could not find any evidence supporting these rumors.

[22] The *Rotterdamsche Courant* gives some details about conditions at sea during such episodes of bad weather. It seems to have been consistently the case that if the packet boats could not sail, no other boats from England arrived in Hellevoetsluys.

weather conditions as it was on days when weather conditions did allow for the crossing of ships.

2 Baseline estimates

Based on the arrival of packet boats I can reconstruct when information reached Amsterdam. This is linked to security returns. There are three prices a week available for the Amsterdam market (for Monday, Wednesday and Friday). I calculate returns based on two (Fri-Wed and Wed-Mon) or three day periods (Mon-Fri).[23] I compare stock returns for periods with and without the arrival of new information. The returns that reflected the arrival of new information are labeled 'news returns', those that did not 'no-news returns'. As a first step I present the kernel densities of these news (solid line) and no-news returns (dashed line) for EIC stock in figure 3. (See figures 18 to 21 in appendix D for return distributions for the other 4 securities).[24] At first glance it becomes clear that returns are more volatile after the arrival of new information. Compared to the distribution of no-news returns there are far less returns close to zero in the distribution. Or conversely, the distribution of news returns has considerably more mass in the tails. In other words: the arrival of new information matters.

[Figure 3 about here]

Table 2 presents the first four moments of the return distributions for periods with ($N_t = 1$) and without new information ($N_t = 0$). Most importantly, and consistent with figure 3, the variance of returns is higher for periods with news. This is consistently true for all securities. In addition, the fraction of zero returns is significantly higher during no-news periods. The ratio of return variances ($\frac{var\left(\Delta p_t^{AMS}|N_t=0\right)}{var\left(\Delta p_t^{AMS}|N_t=1\right)}$) indicates how important factors other than the arrival of news are for returns. Table 2 shows that this fraction lies between

[23]Note that the three day period includes the weekend. During the 18$^{\text{th}}$ century, trading continued during the weekend. However, trade on Sunday was limited due to the absence of Christian traders. Likewise, Jewish traders did not participate on Saturdays (Spooner 1983, p. 21). There is no evidence for more or less volatility over the weekend. See table 14 in appendix F. The 3 day weekend returns are therefore not scaled down.

[24]The Amsterdam EIC return in response to PM Fox' speech on November 28, 1783 is omitted in all variance calculations. This observation is such an outlier that it has a disproportionate effect on the variance of EIC news returns.

0.39 and 0.64 (depending on the stock). This ratio is statistically significantly different from 1.[25] Factors other than news affect returns during both news and no-news periods. After this has been taken into account, between 50 and 75% of the total return variance cannot be attributed to the arrival of news.

[Table 2 about here]

It is possible that Amsterdam investors traded significantly less on days without news. This would imply that price changes in the absence of news are economically less relevant. In appendix C I present information about the timing of a sample of transactions in the Amsterdam market and I show that this was not the case. There was no tendency to trade less on no-news days.

These findings suggest that there were important inefficiencies in the Amsterdam market. However, it is possible that in addition to public news, private information was important as well (see section 1). If private information was not immediately incorporated into prices after the arrival of a packet boat, it would also affect prices during no-news periods. In that case the simple analysis of this section would overestimate the size of inefficiencies in this market. In section 6 I therefore estimate a structural model to take the impact of private information into account. Before presenting these results, the next sections of the paper will first discuss a number of key features of the historical experiment. This will lay the foundations for a number of crucial assumptions of the structural model.

3 Identification of news flows

3.1 The direction of news flows

The historical record suggests that during 1771-1777 and 1783-1787 the dominant fraction of news had its origin in London (see section 1). In this section I provide empirical evidence that London prices had an important impact on Amsterdam prices, but not *vice versa*. In

[25] Because the return series are non-normal (see the Kurtosis measures in table 2), a standard F test on the equality of variances cannot be applied. I follow Boos and Brownie (2004) and use a non-parametric test based on mean absolute deviation from the median. The most widely used test is the Brown-Forsythe (B-F) test.

addition, I provide evidence that information from a third source (such as Paris) did not play an important role.

3.1.1 London and Amsterdam

Firstly, I analyze the flow of information between London and Amsterdam in a simple econometric framework. This framework takes explicitly into account that communication lags varied and boats arrived in a discrete way. I focus on news-returns in Amsterdam and I relate these to the returns in London that were observed in Amsterdam after the arrival of a boat. The Amsterdam news returns $\Delta p_t^{AMS,news}$ is defined as in section 2. The London news return that is observed in Amsterdam, $\Delta \widetilde{p}_{t-1}^{LND}$, is defined as the return in London between the departure of two boats. Similarly, I calculate London news returns $\Delta p_t^{LND,news}$ and the Amsterdam returns that are observed in London, $\Delta \widetilde{p}_{t-1}^{AMS}$. I run the following two regressions

$$\begin{aligned}\Delta p_t^{AMS,news} &= \alpha_0 + \alpha_1 \Delta \widetilde{p}_{t-1}^{LND} + \varepsilon_t \\ \Delta p_t^{LND,news} &= \beta_0 + \beta_1 \Delta \widetilde{p}_{t-1}^{AMS} + \varepsilon_t\end{aligned}$$

Estimates are presented in table 1. Since detailed London price data is only available for the EIC, BoE and the 3% Annuities, results are only available for these three securities. The table shows that London price changes had a lot of explanatory power in Amsterdam, but not the other way around.[26]

[Table 1 about here]

In Appendix B I perform a similar analysis using a Vector Error Correction Model (VECM). The advantage of a VECM is that it takes explicitly into account that Amsterdam and London prices were co-integrated (compare Dempster et al. 2000). The disadvantage of this framework is that one cannot account for the fact that lag lengths varied and that boats arrived in a discrete way. Results are virtually the same.

[26] Note that the coefficients on $\Delta \widetilde{p}_t^{LND}$ are significantly smaller than 1. This is likely the result of the fact that London prices reflect non-news related factors as well and this biases coefficients downwards. In section 5 I take this explicitly into account when I estimate a structural model.

Secondly, I check whether the volatility in the London market was higher after the arrival of information from Amsterdam. If (close to) all relevant information originated in London then the arrival of news from Amsterdam should have no impact on the return variance in London. Results are presented in table 3. Indeed, there seems to be no difference in return variance in London between days with and without news from Amsterdam. If anything, volatility is higher on days without news from Amsterdam. However, this difference is only statistically significant for the 3% Annuities.

[Table 3 about here]

This result is not just important for determining whether news from Amsterdam was important or not. It also gives some additional insight in what the impact of packet boats was on stock markets in general. In addition to news, the packet boats also brought in private letters. Apart from detailed information, these letters could also contain other things like buy or sell orders (see footnote on p.11). It is possible that these orders drove volatility on news days that was independent of any actual news. The results in table 3 suggest that this was not the case. The possible presence of Amsterdam orders on the London market did not have an impact on volatility. Based on this finding, it seems unlikely that London orders did have a significant impact in Amsterdam (for further evidence see section 6).

3.1.2 News from other sources

So far I have focused on London and Amsterdam, but of course it is possible that news originated from a third place, most importantly France, the US or the East Indies. France played an important role in the international politics of the time. I collected data on two periods in which developments in France were relatively unimportant. Nevertheless, they could still have played a role. On average, news from Paris would arrive in London and Amsterdam at the same time.[27] This means that if France was important for pricing the English securities, we would expect to see a positive correlation between London and Amsterdam

[27] I have no information about the exact arrival of news from France in Amsterdam. I do know when news from France was published in English and Dutch newspapers. The median time between the moment a piece of news was sent from Paris to London, or from Paris to Amsterdam, and the moment this information was published in the local newspapers was 8 days. Sources: The *Amsterdamsche Courant* and the *Middlesex Journal*.

returns on the same calendar day. I estimate simple univariate regressions. Results indicate that there was virtually no contemporaneous correlation between London and Amsterdam. The regression coefficients for EIC and BoE stock are 0.0914 and -0.0015 with bootstrapped (1000 replications) standard errors of 0.0469 and 0.0480. For the 3% annuities the corresponding coefficient is -0.0619 with bootstrapped standard error of 0.0624. This confirms that information from Paris was not relevant for the pricing of the English securities.

Another source of information was the US. The American War of Independence started in 1775 and had an important impact on the financial situation of the English government. As a consequence English government securities (and related stocks like the BoE and the SSC) were affected from 1775 onwards. The historical record suggests that all relevant information from the US would reach England first before it arrived in Amsterdam. There was no official mail service between the US and Amsterdam: all letters traditionally arrived through England (Ten Brink 1969, p. 22). In addition, a closer inspection of the Dutch newspapers of the period indicates that all America-related information came in with packet boats from London.

There is an additional complication for EIC stock. A significant fraction of relevant news for this company came from Asia. The Dutch also had an important presence in Asia through their own East India Company (VOC). It is therefore possible that news from Asia may have reached Amsterdam through Dutch VOC ships before it reached London. When Amsterdam did not receive any news from England, relevant information could still have arrived from Asia. A closer examination of the *Amsterdamsche Courant* suggests that this worry is of minor importance. First of all, there were more English ships sailing between Asia and Europe than Dutch ones. As a result, the *Amsterdamsche Courant* often mentioned news from the Dutch Indies that was brought in by English ships. Secondly, Dutch boats from the East Indies often docked at the English harbor of Plymouth (see figure 2) to get fresh water and supplies before sailing to Amsterdam. As a result, news from the Dutch East Indies often reached England first. To provide a final check I collected data on the arrival of news from the Dutch East Indies from the *Amsterdamsche Courant*, aided by the work of Bruijn et al. (1979-1985). Figure 22 in Appendix E presents the distributions of returns on EIC stock calculated over periods when no news arrived from England. I differentiate between returns that reflected the arrival of ships from Asia and returns that did not. Figure 22 shows that the arrival of news from Asia did not lead to more volatile EIC prices. Results for the other securities look very similar. I test this more formally in table 12 in Appendix F. The results indicate that the variance of no-news returns on days when ships from Asia arrived was even smaller (although insignificantly) than that on days ships from Asia did arrive. It should be noted however that the number of observations that reflected the arrival of Dutch ships from the East is limited.

3.2 Exogeneity of news

What determined the arrival of packet boats? Was the arrival of news in Amsterdam truly exogenous? Evidence from newspapers of the time show that packet boats always attempted to depart according to schedule. This is the first important factor determining the arrival of news. Secondly, the weather data available for the period suggest that the total sailing time between Harwich and Hellevoetsluys was largely determined by the direction of the wind. I test this in the following way. Sailing boats do not need to sail parallel to the wind. For example, they can adjust their sails to sail perpendicular to the wind. However, when they get too close to the wind, sails cannot be adjusted anymore as a sailing boat enters the so-called no-go zone; see figure 4. If the boat's direction lies within this no-go zone, it will have to tack. In other words, it will constantly have to change direction, leading to both a longer sailing distance and time at sea. Unfortunately, there is no information available for conditions at sea. However, there is data available on wind directions from the observatory of Zwanenburg (close to Amsterdam) for 2 or 3 times a day. For every observation I determine whether a sailing boat sailing East from Harwich to Hellevoetsluys (see figure 2) would face a no-go zone. For modern sailing boats this no-go zone lies around 30 to 50 degrees from the wind-direction. To be on the safe side, I assume that 18^{th} century packet boats had a no-go zone of 55 degrees around the prevailing wind direction. For each trip I determine what fraction of wind observations observed during that trip were in the no-go zone. The correlation between sailing times and the fraction of no-go zone observations is 0.47. Figure 5 presents this relation graphically. I divide the sample of sailing trips into subsamples according to the fraction of no-go zone observations (0, 0 - 0.25, 0.25 - 0.5, 0.5 - 0.75 and 0.75 - 1). Figure 5 presents the distributions of sailing times for each of these subsamples in the form of boxplots. The figure demonstrates that, to a large extent, the length of a sailing trip was determined by wind conditions.

[Figure 4 about here]

[Figure 5 about here]

3.3 Slipping through of news

Because of its efficiency and official status, the packet boat service was the most important channel for English news to reach the Dutch Republic. Nevertheless, it is not unthinkable that at times news reached Amsterdam in alternative ways. How important was this slipping through of news for share price fluctuations in Amsterdam and does this seriously bias the previous results downwards?

The most important alternative would have been the use of private ships. The packet boat service allowed for two crossings a week. Investors may have used private boats to get information from England on the days the official boats were not sailing. No-news returns could be driven by these unofficial news flows. I use the variation in weather conditions on the North Sea to investigate this issue. Sailing boats relied on the weather to get across the North Sea. I restrict the sample to periods where, after the arrival of a packet boat, wind conditions suddenly turned so that future packet boats were significantly delayed. I assume that during these periods it was equally impossible for other boats to get across.

I construct these bad weather samples in three different ways. First of all I distinguish between no-news periods that were purely the result of the sailing schedule and those that were the result of bad weather. I combine the sailing schedule with a median travelling time of 4 days. I then check for every no-news observation whether the sailing schedule predicted this to be a no-news observation or not. If not, I include this observation in bad weather sample A.

Bad weather sample B is based on wind directions. Returns in Amsterdam are measured over 2 or 3 day periods. For every return I determine what the average daily wind direction was during this 2 or 3 day period. Hellvoetsluys was exactly East (90 degrees) from Harwich. If the average wind condition was from an eastern direction (from 0 to 180 degrees) on every single day, I include the observation in bad weather sample B. I do something similar for bad weather sample C. Here I look at the no-go zones mentioned on page 18. For every day of the 2 or 3 day periods, I check how many wind observations within that day (out of a total of 2 or 3) featured a no-go zone. If for every day at least 2 of these daily wind observations feature a no-go zone, I include this return in bad weather sample C.

Figure 6 presents the kernel densities of EIC returns for no-news periods differentiated by good and bad weather (definition A, see figures 24 and 24 in Appendix E for definitions B and C). Differences between good and bad weather episodes are small. In table 4 I present the corresponding summary statistics for all 5 stocks. In general, the variance of no-news returns was slightly lower during bad weather episodes. However, the difference in the variance between good and bad weather episodes is not statistically significant. These results suggest that the slipping through of news played a minor role.

[Figure 6 about here]

[Table 4 about here]

4 Underreaction and reversals

In this section I test whether the Amsterdam market responded in an efficient way to the arrival of news. Specifically, I check whether Amsterdam prices initially underreacted to the arrival of public information.[28] This could have important implications for the analysis. If prices in Amsterdam initially underreacted to news, subsequent non-news returns would

[28] See for example Huberman and Regev (2001), Chan (2003), Cohen and Frazzini (2008), Carvalho et al. (2009), DellaVigna and Pollet (2009); Hirshleifer et al. (2009); Tetlock (2010b), Savor (2011) and Gilbert et al. (2011). See Hong and Stein (2001) for a useful discussion.

still be related to the incorporation of public information. It is not clear that this should be counted as an inefficiency. I test for this by looking at the time series properties of returns in Amsterdam. Initial underreaction to news should lead to return continuation or momentum (Hong and Stein 2001). I find only limited evidence for momentum. In addition, it is quantitatively unimportant in explaining the variance of non-news returns.[29]

There is as second reason why the time series analysis is important. The presence of noise would imply that returns in Amsterdam exhibit reversals. It is natural to assume that noise shocks are transitory and revert over time - otherwise it would not be noise. If noise was indeed important, as suggested by the baseline analysis, then we should observe return reversals in the Amsterdam market. This is supported by the empirical evidence.

How do I identify momentum and return reversals at the same time? Simple autocorrelation coefficients will aggregate the effects of momentum and reversals - effectively cancelling out the two effects. Instead I differentiate between news and non-news periods and I use the London return to approximate news shocks and identify momentum. More specifically, I perform the following analysis. For all returns in Amsterdam I determine whether news was received from London during the previous period ($N_{t-1} = 1$). I estimate two different equations for $N_{t-1} = 0, 1$:

$$\Delta p_t^{AMS} = \alpha_0 + \alpha_1 \Delta p_{t-1}^{AMS,news} + \alpha_2 \Delta \widetilde{p}_{t-2}^{LND} + \varepsilon_t \text{ if } N_{t-1} = 1 \quad (1)$$

$$\Delta p_t^{AMS} = \beta_0 + \beta_1 \Delta p_{t-1}^{AMS,no-news} + \varepsilon_t \text{ if } N_{t-1} = 0 \quad (2)$$

where $\Delta p_{t-1}^{AMS,news}$ and $\Delta p_{t-1}^{AMS,no-news}$ are the Amsterdam news or no-news returns for the previous period $t-1$. N_{t-1} indicates whether any news was received in this period $t-1$ or not. If so, $\Delta \widetilde{p}_{t-2}^{LND}$ is the London news return observed in Amsterdam.

Equation (1) uses observations for which $N_{t-1} = 1$. It measures the degree of reversal of Amsterdam returns (α_1) and the degree to which returns in Amsterdam responded to returns

[29] It might seem obvious that a VEC framework would be most suitable to test for intial underreaction. However, it can be shown that, due to the presence of noise, such a framework suffers from errors-in-variables problems. The coefficient on the Error Correction would not only capture a delayed response to news, it would also reflect the reversal of noise shocks. There is no clear way to separate these two things in a VEC framework.

in London that were observed during the previous period (α_2). The latter measures the slow response to news from London and is equivalent to return continuation or momentum. Equation (2) only uses observations where $N_{t-1} = 0$ and measures the degree of return continuation (β_1). If noise is covariance stationary, then we would expect that $\alpha_1 = \beta_1$. In order to fully utilize the available data and to arrive at correct standard errors, I estimate the two equations jointly using seemingly unrelated estimation (SUEST). There is one problem with this estimation. $\Delta\widetilde{p}_{t-2}^{LND}$ is not a perfect measure of news because returns in London presumably reflect noise as well. This means that equation (1) is likely to be misspecified. Specifically, α_2 is biased downwards and the statistical equivalence of α_1 and β_1 will not necessarily hold. In section 6 I return to this point and I estimate a simple structural model that addresses these issues. Regression results are presented in table 5. Because London price data only cover EIC and BoE stock and 3% Annuities, results are restricted to these three securities.

[Table 5 about here]

As expected there is ample evidence for reversals, both in the presence and absence of news. For the BoE and the 3% Annuities, both α_1 and β_1 are negative and not statistically different from each other. For the EIC only β_1 is negative, α_1 is positive (but close to zero) and statistically different from β_1. The evidence in favor of momentum is weaker. α_2 is positive for all three securities but small and statistically insignificant. Overall, the size of the momentum and reversal estimates are surprisingly similar to modern estimates of reversals and momentum (e.g. Tetlock 2010a, table 1).

How much does this momentum matter for the fraction of return variance that can be attributed to the arrival of news? In table 5 I redo the benchmark return variance estimates from table 2 adjusting the no-news returns for momentum. Specifically, I use the estimates of α_2 to determine what part of the Amsterdam no-news returns can be attributed to momentum and I adjust the variance accordingly. News returns are left unchanged. The results indicate that the (weak) presence of momentum has virtually no impact on the volatility estimates.

[Table 5 about here]

5 News vs the transmission of noise

It is possible that London prices contained noise and that this affected prices in Amsterdam. This does not affect the volatility in the absence of news (the focus of this study), but it would inflate the variance of news returns (the efficient benchmark). Arguably, we should not consider the Amsterdam response to London noise an inefficiency. Markets are efficient when they respond to all available information. If that information is the London price, then it would be hard to argue that the Amsterdam market was inefficient when it responded to that price. Nevertheless, it is of interest to know to what extent Amsterdam news returns reflected noise and to what extent they moved in response to news. In this section, I perform a number of empirical tests, and the results suggest that the response to London noise was quantitatively unimportant.

First of all, it is important to note that Amsterdam investors did not only observe London price changes. They observed all available public information. This means that they could filter out noise from the London price and only respond to actual news. Second, arbitrage between London and Amsterdam was imperfect. Due to delays in communication an arbitrage operation would effectively take eight days or more. Why does this matter? We can assume that noise is transitory and reverts over time - otherwise it would not be noise. If noise in the London price was expected to revert within this eight day period, it should not have affected prices in Amsterdam. Moreover, arbitrage was risky - a lot could happen in an eight day period. This restricted overall arbitrage and the incorporation of London noise into Amsterdam prices.

There are three pieces of suggestive evidence that support these arguments. First of all, the regression results in table 1 indicate that price changes in Amsterdam after the arrival of a boat did not respond one to one to price changes in London. The regression coefficient is approximately 0.4. This does not reflect a slow response to news (see table 5) but indicates that London price changes contained noise and that this noise was not (fully) incorporated into Amsterdam prices.

Secondly, the market in Amsterdam moved relatively independently from London in the short run. Figure 7 presents the distributions of price differences between London and Amsterdam for EIC stock before and after the response to news from England (see figure 25 and 26 in Appendix E for BoE stock and the 3% Annuities). The figure indicates that price differences narrowed after the arrival of a boat (more mass around zero) but remained significant.

[Figure 7 about here]

Thirdly, if arbitrage led to the incorporation of London noise into Amsterdam prices we would also expect to see the reverse: the incorporation of Amsterdam noise into London prices. Otherwise arbitrage would work asymmetrically. The results in section 3 provide no evidence for this. Table 1 shows that after the arrival of a boat from Amsterdam, London prices did not respond to information about price changes in London. The variance of returns was not even higher on the days news from Amsterdam arrived (see table 3).

I provide a more formal test for the possible incorporation of London noise into prices in Amsterdam. The key assumption for this analysis is that noise shocks are transitory and are reverted later on. If noise was transmitted from London to Amsterdam we should therefore expect that London returns should predict subsequent reversals in Amsterdam. This is not the case. To test this, I run the following regression:

$$\Delta p_{t+T}^{AMS} = \alpha_0 + \alpha_1 \Delta \widetilde{p}_{t-1}^{LND} + \varepsilon_t$$

where $\Delta \widetilde{p}_{t-1}^{LND}$ is the return observed in London before the departure of a boat. Δp_{t+T}^{AMS} is the future Amsterdam return. This return is measured over period T after the London news has been incorporated into Amsterdam prices. T ranges from a period of the next 2-3 days to 4 weeks (estimates for longer horizons are available upon request). Estimates for EIC stock are presented in panel (2) of table 6. Tables 15 to 16 in Appendix F present the estimates for BoE stock and the 3% Annuities. None of the three stocks exhibit any (negative) predictability **across** markets, independent of what time horizon is used. This suggests that noise did not migrate from the London to the Amsterdam market.

[Table 6 about here]

For comparison, panels (1) and (3) in tables 6 and 15 and 16 (Appendix F) present estimates of predictability **within** the Amsterdam and London markets. In these panels the current Amsterdam (London) 2-3 day return is used as a predictor of future Amsterdam (London) returns. Consistent with the results from table 5, for the BoE and the 3% Annuities there is evidence for within-market reversals at relatively short time horizons up to approximately one week. This demonstrates the presence of noise and suggest that noise reverted within a week. After a week the coefficients turn (slightly) positive and become statistically insignificant (for the EIC no negative auto-correlation seems to be present, compare table 5). This might explain why there was no negative auto-correlation between markets (and apparently no transmission of noise shocks). An arbitrage operation took eight day on average and within this time frame the noise shocks would have disappeared, making the arbitrage operation futile.

6 Structural model

The results of section 2 demonstrate that the prices of English securities in Amsterdam moved considerably in the absence of news. Between 50 to 75% of the overall return variance was seemingly unrelated to the arrival of information from England. It is not clear that this percentage only reflects inefficiencies in the market. It is possible that in addition to public news, private information was important as well. Research on current day markets indicates that private information plays an important role (see inter alia Hasbrouck 1991; Easley et al. 1997). Anecdotal evidence suggests that the 18^{th} century was no different. English insiders used both the London and the Amsterdam market to benefit from their private signals (see section 1). In addition to public news, the packet boats also transmitted private signals to Amsterdam. London insiders would inform their agents in Amsterdam about their private signal and these agents would trade on the information. It is likely that this set into motion a process of price discovery that affected prices both right after the arrival of a boat and during subsequent during no-news periods (Kyle 1985; Glosten and Milgrom 1985).

I estimate a structural model to take the impact of private information into account. The results suggest that private information had an important role. After taking its impact into account only between 20 and 50% of the overall return variance remains unexplained. The structural model allows for two additional extensions. First of all, I allow the variance of the noise trading shocks in Amsterdam to be different across news and no-news periods. Secondly, the framework can accommodate the (possible) initial underreaction to information. Neither extension is quantitatively important.

The identification of the structural model is based on the covariance of price changes in Amsterdam and London. The idea is as follows. Prices in both Amsterdam and London should reflect the arrival of new information. As this information gets incorporated into prices, the two markets move in the same direction. The covariance reflects how important information is for the overall variance of price changes and what fraction of the return variance is unrelated to new information.

Figure 8 presents the intuition behind the analysis. Public news and private information arrive continuously in London. By assumption, public news in London is immediately incorporated into prices in Amsterdam. At certain points in time a mail boat leaves to transmit this information to Amsterdam. After the arrival of the boat, Amsterdam prices incorporate this news as well. The co-movement of London prices **before** departure and Amsterdam prices **after** arrival of the mail therefore reflects the impact of public news.

Private information might not be immediately incorporated into prices in London. Some of it may be publicly revealed before the departure of a boat (in fact becoming public news), but it is likely that a significant fraction remains private. These private signals are also transmitted to the Amsterdam market. This private information may not be immediately incorporated into prices in Amsterdam either, and may affect Amsterdam prices not just after the arrival of a boat but also in subsequent no-news periods. At the same time it also affects the contemporaneous (but as of yet unreported) returns in London as the private signal is incorporated into prices there as well. The co-movement between Amsterdam price changes **after** the arrival of a boat and London returns **after** the departure of that boat should therefore reflect the revelation of private information. The Amsterdam return variance that cannot be explained by either type of information is assumed to be noise.

[Figure 8 about here]

I rely on structural estimation to implement this intuition. Simple OLS or a VEC model are of limited use for this specific analysis because of error-in-variable problems and attenuation bias. London prices are probably driven by noise as well. Simply regressing London on Amsterdam price changes will therefore bias the impact of information downwards. I follow De Jong and Schotman (2010) and I rely on covariances (instead of regression coefficients) to identify the primitives of the structural model.

6.1 Baseline

I assume that London price changes between the departures of two boats can be written as

$$\Delta \widetilde{p}_t^{LND} = \eta_t + \varepsilon_t + v_t$$

where η_t and ε_t are public and private signals respectively that are revealed in London over period t. η_t is unknown to everyone at the beginning of t and is revealed to the public during the course of the period. ε_t is determined by nature at the beginning of period t and is privately observed by an insider. The insider immediately sends this information to his agent in Amsterdam who observes it at the beginning of Amsterdam period t (see figure 8). For simplicity I assume that ε_t is fully revealed to the public by the end of t. This way I can leave the price discovery process in London unmodeled.[30] $\eta_t \sim N\left(0, \sigma_\eta^2\right)$ and $\varepsilon_t \sim N\left(0, \sigma_\varepsilon^2\right)$ are assumed to be independent and iid. $v_t \sim N\left(0, \sigma_v^2\right)$ is a residual and captures noise. v_t is assumed to be independent of η_t and ε_t. By the end of t, the (public) information about

[30] This setting could accomodate private information that is longer lived, as long as innovations are iid. In that case there would be multiple private signals to keep track of at the same time. Results remain unchanged though as the (total) covariance that can be attributed to the revelation of private information stays the same.

the realizations of η_t and ε_t is transmitted to Amsterdam, which arrives at the beginning of Amsterdam period $t+1$.

In Amsterdam, period t can have two sub-periods denoted $t,1$ and $t,2$. Period $t,1$ is a news period that takes place when news from London has just arrived in Amsterdam. Period $t,2$ is a no-news period that only happens if the time between two boat arrivals is sufficiently long. The Amsterdam news-return in $t,1$ is written as

$$\Delta p_{t,1}^{AMS} = \widetilde{\eta}_{t-1} + \lambda_1 \theta_{t,1} + w_{t,1}$$

and consists of three parts. $\theta_{t,1}$ is a noisy signal of private information ε_t that is transmitted by the London insider to his agent in Amsterdam. The Amsterdam agent trades on this information and I assume that his trades are not fully informative. Instead, he generates a noisy signal $\theta_{t,1}$ with $\theta_{t,1} \sim N\left(0, \sigma_{\theta_1}^2\right)$ and $cov(\varepsilon_t, \theta_{t,1}) = \sigma_{\varepsilon}^2$. $\lambda_1 \theta_{t,1}$ captures the response in Amsterdam to this imperfect information revelation. Applying the projection theorem it can be shown that

$$\lambda_1 = \frac{\sigma_{\varepsilon}^2}{\sigma_{\theta_1}^2} \tag{3}$$

The Amsterdam news return $\Delta p_{t,1}^{AMS}$ also responds to public information $\widetilde{\eta}_{t-1}$. This consists both of the public signal η_{t-1} and that part of private signal ε_{t-1} that was not yet incorporated into Amsterdam prices during the previous period (note that I assume that ε_{t-1} is made public in London the moment the boat departs for Amsterdam). Finally, the Amsterdam price change contains a noise shock $w_{t,1} \sim N\left(0, \sigma_{w_1}^2\right)$ which is assumed to be independent from ε_t, $\widetilde{\eta}_{t-1}$and v_t. It put no restrictions on $cov(\theta_{t,1}, w_{t,1})$, i.e $w_{t,1}$ can be related to the noisy component of $\theta_{t,1}$.

The Amsterdam no-news return in $t,2$ is written as

$$\Delta p_{t,2}^{AMS} = \left(\widehat{\lambda}_1 - \lambda_1\right) \theta_{t,1} + \widehat{\lambda}_2 \theta_{t,2} + w_{t,2} \tag{4}$$

First of all the agents for the London insider keep trading on the private signal. This trading generates an additional signal $\theta_{t,2}$, with $\theta_{t,2} \sim N\left(0, \sigma_{\theta_2}^2\right)$ and $cov(\varepsilon_t, \theta_{t,2}) = \sigma_{\varepsilon}^2$. The two available signals, $\theta_{t,1}$ and $\theta_{t,2}$, are given respective weights $\widehat{\lambda}_1$ and $\widehat{\lambda}_2$. These signals can be correlated[31] and this means that, compared to the first period, the weight on signal $\theta_{t,1}$ could change. This is captured by $\left(\widehat{\lambda}_1 - \lambda_1\right)$. Applying the projection theorem it can be shown that

$$\widehat{\lambda}_1 = \lambda_1 - \widehat{\lambda}_2 \frac{cov(\theta_1, \theta_2)}{\sigma^2_{\theta_1}} \tag{5}$$

$$\widehat{\lambda}_2 = \lambda_2 - \widehat{\lambda}_1 \frac{cov(\theta_1, \theta_2)}{\sigma^2_{\theta_2}} \tag{6}$$

$$\text{with } \lambda_2 = \frac{\sigma^2_{\varepsilon}}{\sigma^2_{\theta_2}} \tag{7}$$

Finally, $\Delta p^{AMS}_{t,2}$ reflects an additional noise shock $w_{t,2} \sim N\left(0, \sigma^2_{w_2}\right)$ that is allowed to covary with $\theta_{t,2}$ and w_1 but assumed independent of ε_t, $\widetilde{\eta}_{t-1}$ and v_t.

The covariances with price changes in London uncover what fraction of the return variance in Amsterdam can be attributed to public and private information.

$$cov\left(\Delta p^{AMS}_{t,1}, \Delta \widetilde{p}^{LND}_{t-1}\right) = cov\left(\widetilde{\eta}_{t-1}, \eta_{t-1} + \varepsilon_{t-1}\right) = \sigma^2_{\widetilde{\eta}} \tag{8}$$

$$cov\left(\Delta p^{AMS}_{t,1}, \Delta \widetilde{p}^{LND}_{t}\right) = \lambda_1 \sigma^2_{\varepsilon} \tag{9}$$

$$cov\left(\Delta p^{AMS}_{t,2}, \Delta \widetilde{p}^{LND}_{t}\right) = \left(\widehat{\lambda}_1 - \lambda_1 + \widehat{\lambda}_2\right) \sigma^2_{\varepsilon} \tag{10}$$

$cov\left(\Delta p^{AMS}_{t,1}, \Delta \widetilde{p}^{LND}_{t-1}\right)$ simply measures how large the return variance is that can be attributed to the arrival of public information $\widetilde{\eta}_{t-1}$. Without making stronger assumptions about the price discovery process, it cannot be determined what fraction of $\sigma^2_{\widetilde{\eta}}$ can be attributed to public signal η and that part of private signal ε that is not yet incorporated into prices.

$cov\left(\Delta p^{AMS}_{t,1}, \Delta \widetilde{p}^{LND}_{t}\right)$ and $cov\left(\Delta p^{AMS}_{t,2}, \Delta \widetilde{p}^{LND}_{t}\right)$ measure the impact of the (noisy) incorporation of private information on the variance of returns.[32] To see this plug (3) and (5)-(7)

[31] This is not necessarily the case. In a strategic two-period Kyle-model it can be shown $cov(\theta_{t,1}, \theta_{t,2}) = 0$.

[32] The full response to the noisy signal is contributed to market efficiency. Only $w_{t,1}$ and $w_{t,2}$ capture market inefficiencies as they are not related to the incorporation of news at all.

into the expressions for $var\left(\Delta p_{t,1}^{A}\right)$

$$\begin{aligned} var\left(\Delta p_{t,1}^{AMS}\right) &= \sigma_{\tilde{\eta}}^{2} + \lambda_{1}^{2}\sigma_{\theta_1}^{2} + \sigma_{w_1}^{2} \\ &= \sigma_{\tilde{\eta}}^{2} + \underbrace{\lambda_{1}\sigma_{\varepsilon}^{2}}_{cov\left(\Delta p_{t,1}^{AMS},\Delta\tilde{p}_{t}^{LND}\right)} + \sigma_{w_1}^{2} \qquad (11) \end{aligned}$$

and $var\left(\Delta p_{t,2}^{A}\right)$

$$\begin{aligned} var\left(\Delta p_{t,2}^{AMS}\right) &= \left(\widehat{\lambda}_{1} - \lambda_{1}\right)^{2}\sigma_{\theta_1}^{2} + \widehat{\lambda}_{2}^{2}\sigma_{\theta_2}^{2} \\ &\quad +2\left(\widehat{\lambda}_{1} - \lambda_{1}\right)\widehat{\lambda}_{2}cov\left(\theta_{t,1},\theta_{t,2}\right) + \sigma_{w_2}^{2} \\ &= \underbrace{\left(\widehat{\lambda}_{1} - \lambda_{1} + \widehat{\lambda}_{2}\right)\sigma_{\varepsilon}^{2}}_{cov\left(\Delta p_{t,2}^{AMS},\Delta\tilde{p}_{t}^{LND}\right)} + \sigma_{w_2}^{2} \qquad (12) \end{aligned}$$

Together with (8) - (10), expressions (11) and (12) identify the impact of noise shocks w_1 and w_2. I estimate the structural model using GMM. Estimates are presented in table 7 (see table 17 in Appendix for the number of observations associated with the moment conditions).[33]

[Tables 7 - 17 about here]

The results demonstrate that private information has an impact on both Amsterdam news and no-news returns. This impact is statistically significant in most of the cases, except for returns on 3% Annuities during news periods. Table 8 decomposes the variance of stock returns into its different components. Information explains a large fraction of overall volatility. Public news explains between 30 and 40% of overall volatility. The discovery of private information explains between 20 and 40%. Between 20 and 50% of the return variance cannot be attributed to the incorporation of information and indicates how large market inefficiencies were.

[33] For the purpose of this exercise I add up all no-news returns of a given no-news period to arrive at $\Delta p_{t,2}^{A}$. I do this to keep the empirics consistent with the structural model. In most cases no-news periods feature only one no-news return, but occasionally a no-news period was so long that multiple returns are available. However, there are not enough observations to model this separately and arrive at sensible parameter estimates. As a result the variance of no-news returns is slightly higher in table 7 than in the baseline of table 2.

6.2 Under- or overreaction to news

One of the main assumptions of the previous analysis is that prices in Amsterdam immediately incorporated all available information and that there was no (initial) underreaction to news. There is a only a small degree of momentum in the return series (see table 5 in section 4) which suggests that this assumption is (approximately) valid. Nevertheless, these estimates might be affected by measurement problems. I introduce initial underreaction to news into the structural model to investigate this further. Note that initial underreaction to news is equivalent to the presence of a correlation between news shocks and noise in Amsterdam (see De Jong and Schotman 2010).[34] By allowing for initial underreaction I therefore also relax the assumption that noise and news were uncorrelated.

The framework of the previous section can be easily extended to accommodate underreaction. The changes in the efficient information sets can be expressed as

$$\begin{aligned}\Delta I_{t,1}^{A} &= \lambda_1(\varepsilon_t + u_{t,1}) + \widetilde{\eta}_{t-1} + w_{t,1} \\ \Delta I_{t,2}^{A} &= \left(\widehat{\lambda}_1 - \lambda_1\right)(\varepsilon_t + u_{t,1}) + \widehat{\lambda}_2(\varepsilon_t + u_{t,2}) + w_{t,2}\end{aligned}$$

Now suppose that initial underreaction immediately gets resolved in the next period.[35] In that case Amsterdam price changes can be written as

$$\begin{aligned}\Delta p_{t,1}^{A} &= \beta\Delta I_{t,1}^{A} + (1-\beta)\Delta I_{t-1,1}^{A} + w_{t,1} \text{ if period } t-1 \text{ only had a subperiod 1 } (...|_{t-1,1}) \\ \Delta p_{t,1}^{A} &= \beta\Delta I_{t,1}^{A} + (1-\beta)\Delta I_{t-1,2}^{A} + w_{t,1} \text{if period } t-1 \text{ also had a subperiod 2 } (...|_{t-1,2}) \\ \Delta p_{t,2}^{A} &= \beta\Delta I_{t,2}^{A} + (1-\beta)\Delta I_{t,1}^{A} + w_{t,2}\end{aligned}$$

where $\beta < 1$ indicates initial underreaction to information. I assume that London prices incorporate all relevant information efficiently, in other words $\Delta p_{t-1}^{L} = \eta_{t-1} + \varepsilon_{t-1} + v_{t-1}$. For the purpose of investigating underreaction in the Amsterdam market this is a reasonable

[34] Define $\Delta I_{t,1}^{AMS}$ and $\Delta I_{t,2}^{AMS}$ as the changes in the information sets in Amsterdam during the news and no-news periods. Then initial undereaction would predict that $cov(\Delta I_{t,1}^{AMS}, w_{t,1}) < 0$ and $cov(\Delta I_{t,2}^{AMS}, w_{t,2}) > 0$.

[35] In theory it might take longer for underreaction to be resolved. Adding more lags to the structural model did not lead to significant results.

assumption. As before, the covariances between Amsterdam and London can be used to determine the importance of the incorporation of information for the variance of returns. These are given by the following moment equations:

$$cov\left(\Delta p^A_{t,1}, \Delta p^L_{t-2}|_{t-1,1}\right) \cup cov\left(\Delta p^A_{t,2}, \Delta p^L_{t-1}\right) = (1-\beta)\sigma^2_{\widetilde{\eta}} \quad (13)$$

$$cov\left(\Delta p^A_{t,1}, \Delta p^L_{t-1}|_{t-1,1}\right) = \beta\sigma^2_{\widetilde{\eta}} + (1-\beta)\lambda_1\sigma^2_{\varepsilon} \quad (14)$$

$$cov\left(\Delta p^A_{t,1}, \Delta p^L_{t-1}|_{t-1,1\&t-1,2}\right) = \beta\sigma^2_{\widetilde{\eta}} + (1-\beta)\left(\widehat{\lambda}_1 - \lambda_1 + \widehat{\lambda}_2\right)\sigma^2_{\varepsilon} \quad (15)$$

$$cov\left(\Delta p^A_{t,1}, \Delta p^L_{t}\right) = \beta\lambda_1\sigma^2_{\varepsilon} \quad (16)$$

$$cov\left(\Delta p^A_{t,2}, \Delta p^L_{t}\right) = \beta\left(\widehat{\lambda}_1 - \lambda_1 + \widehat{\lambda}_2\right)\sigma^2_{\varepsilon} \quad (17)$$

The moment conditions identify parameters β, $\sigma^2_{\widetilde{\eta}}$, $\lambda_1\sigma^2_{\varepsilon}$, and $\left(\widehat{\lambda}_1 - \lambda_1 + \widehat{\lambda}_2\right)\sigma^2_{\varepsilon}$. Plugging in for (3) and (5)-(7) and eliminating cross-terms it can be shown that

$$var\left(\Delta p^A_{t,1}|_{t-1,1}\right) = \left[\beta^2 + (1-\beta)^2\right]\left(\lambda_1\sigma^2_{\varepsilon} + \sigma^2_{\widetilde{\eta}}\right) + \sigma^2_{w_1}$$

$$var\left(\Delta p^A_{t,1}|_{t-1,2}\right) = \beta^2\left(\lambda_1\sigma^2_{\varepsilon} + \sigma^2_{\widetilde{\eta}}\right) + (1-\beta)^2\left(\widehat{\lambda}_1 - \lambda_1 + \widehat{\lambda}_2\right)\sigma^2_{\varepsilon} + \sigma^2_{w_1}$$

$$var(\Delta p^A_{t,2}) = \beta^2\left(\widehat{\lambda}_1 - \lambda_1 + \widehat{\lambda}_2\right)\sigma^2_{\varepsilon} + (1-\beta)^2\left(\lambda_1\sigma^2_{\varepsilon} + \sigma^2_{\widetilde{\eta}}\right) + \sigma^2_{w_2}$$

These additional moment conditions identify the impact of noise shocks w_1 and w_2 on overall volatility.

Estimates are presented in tables 18 and 19 in Appendix F. The model is overidentified and a Hansen J-test fails to reject the validity of the model. For EIC stock and the 3% Annuities. the estimates of β are (somewhat) smaller than 1, suggesting there was some initial underreaction to news. However, differences are small and β is not statistically significantly different from 1. In addition, the results suggest that underreaction is quantitatively unimportant for the estimates.

7 Conclusion and discussion

Financial markets are thought to be inefficient when they move too much relative to the arrival of information. How big is this inefficiency? In today's world this is difficult to determine because the arrival of information is hard to identify. In this paper I use a natural experiment from financial history where the flow of information was regularly interrupted for exogenous reasons. I look at the market for English securities in 18^{th} century Amsterdam. Relevant information originated in England and was transmitted to Amsterdam by sailing boats. These boats were scheduled to sail twice a week but depending on weather conditions they were often delayed.

I look at price movements in Amsterdam during periods without news. I show that volatility in the absence of news was considerable - between 50 and 75% of the overall return variance cannot be explained by the arrival of news. In addition to public news, private information was important as well. I estimate a structural model to capture this dimension. Once this is taken into account, 20 to 50 % of the return variance can be attributed to noise. Overall, the results imply that prices in Amsterdam moved too much relative to the arrival of new information but that the majority of price movements were the result of efficient price discovery.

Two other findings from this paper stand out as well. First, this paper explains a larger fraction of volatility with public news (between 25 and 40%) than other studies. This may suggest that modern-day studies suffer from measurement problems, and that market inefficiencies may be smaller than is often thought. Second, price changes in Amsterdam have virtually no effect on returns in London. This finding has important implications for the relevance of discount rate shocks in this setting. Amsterdam investors co-determined the discount rate for English assets. They held between 20 and 30% of the English securities and Amsterdam was the most important international capital market of the period. Shocks to the Amsterdam discount rate affected Amsterdam prices first. Subsequently, the packet boats brought this news to the London market. The fact that Amsterdam prices had virtually no impact on London suggests that the discount rate shocks, at least at the bi-daily frequency studied here, were relatively unimportant. News about cash flows seems to have dominated. This does not necessarily imply that discount factors did not explain a larger share of the return variance at lower (i.e. monthly) frequencies (see inter alia Campbell 1991; Koijen and Van Binsbergen 2010; Cochrane 2011).

This paper follows Garbade and Silber (1978) and uses an historical experiment to identify fundamental economic behavior. As with any historical study, the question is how relevant results are for today. Since the 18^{th} century financial markets and information flows have changed dramatically. First of all, there are many similarities between 18^{th} century markets and the present. While financial markets have become larger and more liquid, many aspects of 18^{th} century markets are strikingly similar to today. This is especially true of London and Amsterdam, which were the most advanced financial markets of the time.[36] For example, my estimates for momentum and return reversals are surprisingly similar to modern figures (compare Tetlock 2010a, see also Neal 1990). Harrison (1998) argues that the return process has changed very little over time and that 18^{th} century markets were not so different from the 1990s. Temin and Voth (2003) document that sophisticated investors' strategies during the South Sea Bubble of 1720 were very similar to those during the more recent Tech bubble. Furthermore, Frehen et al. (2012) show that during this episode market participants were well able to differentiate between systematic and idiosyncratic risk.

Second, data from the days of more primitive communication technology may offer additional insights. What matters is how markets respond to information, not how that information arrives to the market.[37] Using historical data allows for a clean identification of news arrival, something that is impossible in the days of around-the-clock news coverage and instant, long-distance data exchange.

[36] The Amsterdam market for English securities featured trade in spots, futures and options. In addition, there was a developed market for repos (Koudijs and Voth 2012).

[37] It is possible that the market's response to information itself may have changed. More advanced information technology could facilitate more efficient information processing. It is not clear that this is the case. Bai et al (2012) show that even after decades of fast technological progress, markets have not become more informative. In addition, the results of this paper indicate that the Amsterdam market was not slow to respond to information.

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Figures

Figure 1: EIC prices in London and Amsterdam, November 1783

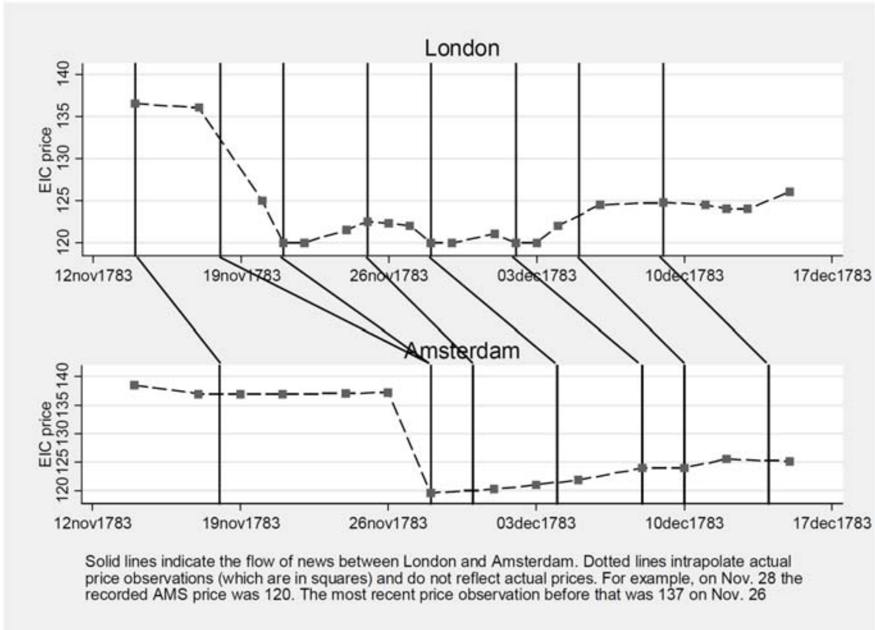


Figure 2: Map North Sea Area

Figure 3: Return distributions EIC

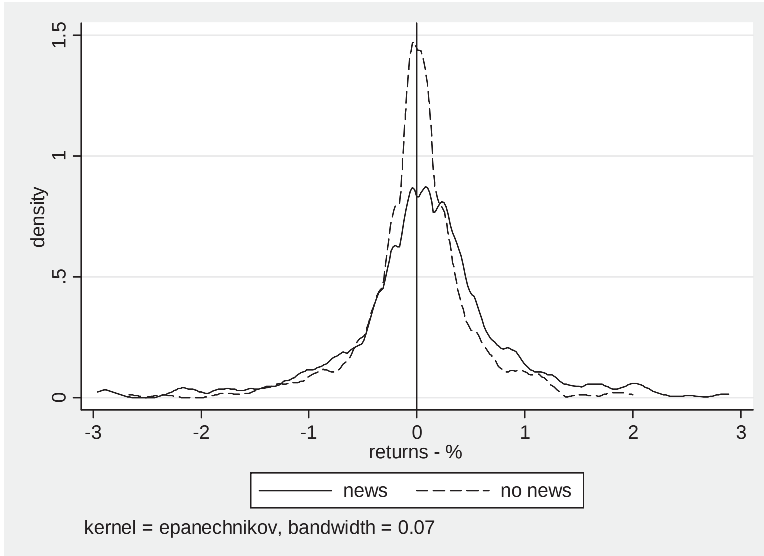


Figure 4: Wind directions and no-go zone

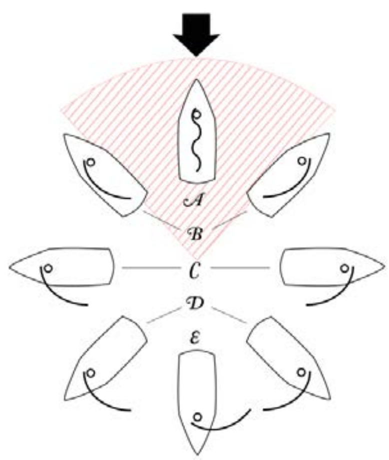


Figure 5: Travelling times and no-go zones

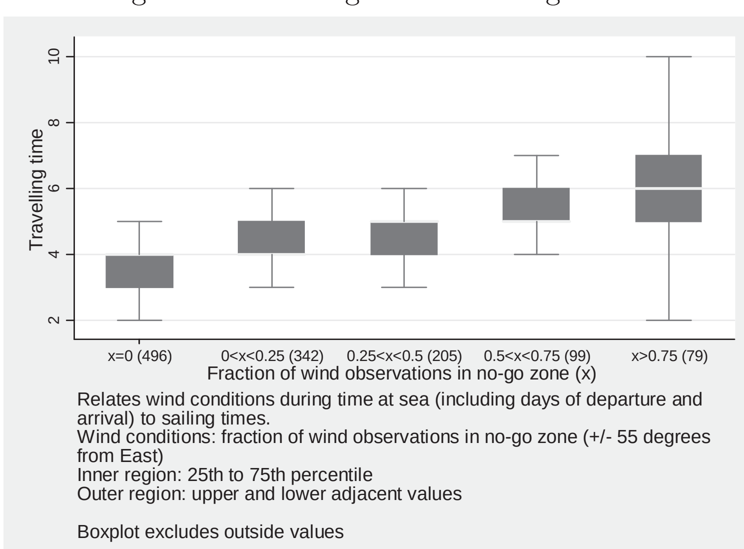


Figure 6: Return distributions EIC - bad weather sample A

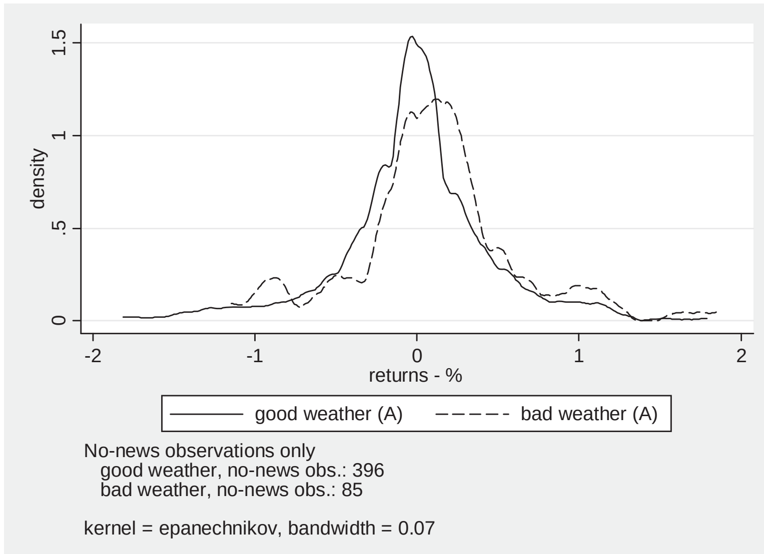


Figure 7: Price differences Amsterdam and London - EIC

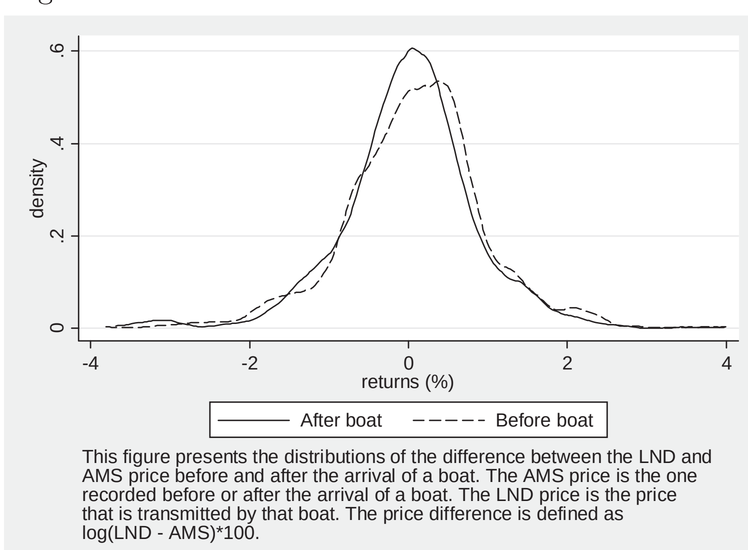
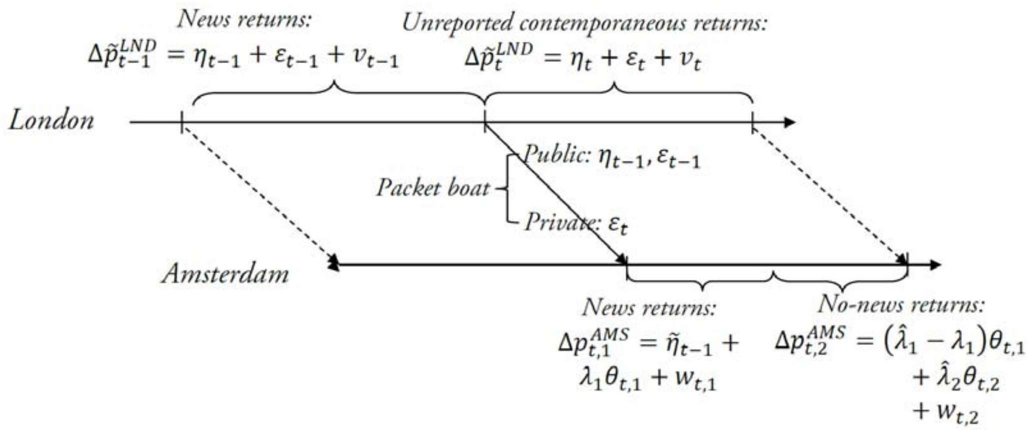


Figure 8: Setup structural model



This diagram illustrates the intuition behind the structural model. The horizontal lines are time axes. The diagonal lines indicate the sailing of packet boats that transmit both public and private information.

Period t in Amsterdam is divided into two sub-periods, $t,1$ is the news period right after the arrival of a boat, $t,2$ is the subsequent sub-period without news.

London returns over period $t-1$ are called news returns: they are observed in Amsterdam after the sailing of a boat. London returns over period t take place after the departure of a boat and, even though they are contemporaneous, they are not yet reported to Amsterdam until the next boat sails.

The impact of public news is measured by the covariance between London and Amsterdam news returns ($cov(\Delta\tilde{p}_{t-1}^{LND}, \Delta p_{t,1}^{AMS})$). Public information transmitted by a boat is given by $\eta_{t-1} + \varepsilon_{t-1}$. The response in Amsterdam to that information is given by $\tilde{\eta}_{t-1}$, which consists of η_{t-1} and that part of private signal ε_{t-1} that is not yet incorporated into Amsterdam prices.

The impact of private information is measured by the covariance between the contemporaneous (but as of yet unreported) London returns and Amsterdam returns over news and no-news periods ($cov(\Delta\tilde{p}_{t}^{LND}, \Delta p_{t,1}^{AMS})$ and $cov(\Delta\tilde{p}_{t}^{LND}, \Delta p_{t,2}^{AMS})$). The intuition behind this is that, as the same private signal is "discovered" in both markets, prices should move in the same direction. Private information transmitted by a boat is given by ε_t. Through the trading process, the market observes noisy signals of ε_t ($\theta_{t,1}$ in $t,1$ and $\theta_{t,2}$ in $t,2$) that may be correlated. The lamdas (λ_1, $\hat{\lambda}_1$, $\hat{\lambda}_2$) are the updating coefficients based on these noisy signals.

Apart from moving in response to public and private information, Amsterdam and London returns are also affected by noise, captured by disturbances v_t and w_t.

Tables

Table 1: Responses to news, AMS and LND

	AMS (response to LND) Δp_t^A			LND (response to AMS) Δp_t^L		
	EIC	BoE	3% Ann.	EIC	BOE	3% Ann.
LND news return	0.373	0.386	0.458			
($\Delta \widetilde{p}_t^L$)	(0.043)***	(0.057)***	(0.064)***			
AMS news return				0.045	0.033	0.044
($\Delta \widetilde{p}_t^A$)				(0.030)	(0.041)	(0.032)
Constant	0.053	0.034	0.046	0.005	0.009	0.014
	(0.029)*	(0.016)**	(0.022)**	(0.030)	(0.019)	(0.016)
N	638	647	668	666	646	757
Adj. R^2	0.20	0.20	0.21	0.00	0.00	0.00

This table presents estimates of the response of 2/3 day returns (Mon-Wed-Fri) in Amsterdam (AMS) and LND (London) to news-returns in the other market. A news return is defined as the most recent price observed in the other market (through packet boat τ) minus the previous price observed (through packet boat $\tau - 1$). A tilde indicates a return in LND (AMS) that is observed in AMS (LND) at AMS (LND) time t.
Robust, bootstrapped (1000 replications) standard errors reported in parantheses.
***, **, * denotes statistical significance at the 1, 5, 10% level respectively.

Table 2: Benchmark results

		Δp_t^{AMS}				
		EIC	SSC	BoE	3% Ann	4% Ann
mean	news ($N_t = 1$)	0.094	0.040	0.051	0.072	0.049
	no-news ($N_t = 0$)	0.010	0.021	0.009	0.005	0.012
variance	news ($N_t = 1$)	0.710	0.309	0.218	0.386	0.283
	no-news ($N_t = 0$)	0.278	0.196	0.139	0.215	0.177
	(B-F statistic)	(42.3)***	(17.0)***	(22.7)***	(19.3)***	(26.7)***
skewness	news ($N_t = 1$)	0.218	0.175	0.540	0.633	−0.030
	no-news ($N_t = 0$)	−0.033	0.808	0.052	−0.620	−0.357
kurtosis	news ($N_t = 1$)	7.55	7.93	7.22	10.60	8.11
	no-news ($N_t = 0$)	8.60	9.51	12.07	11.99	20.66
% zero	news ($N_t = 1$)	13.6	38.1	22.7	29.6	50.6
	no-news ($N_t = 0$)	27.0	54.6	38.2	40.9	65.1
Obs	news ($N_t = 1$)	678	678	678	678	678
	no-news ($N_t = 0$)	482	482	482	482	482
$\frac{var\left(\Delta p_t^{AMS} \mid N_t=0\right)}{var\left(\Delta p_t^{AMS} \mid N_t=1\right)}$		0.391	0.634	0.639	0.557	0.625
Fraction $var(\Delta p_t^{AMS})$ unexplained by news		0.524	0.748	0.752	0.683	0.740

Descriptive statistics of Amsterdam returns over 2 or 3 day periods (denoted t) with or without news ($N_t = 1$ or $N_t = 0$).

Periods: Sept. 1771 - Dec. 1777 and Sept. 1783 - Mar. 1787.

The fraction of $var(\Delta p_t^{AMS})$ that cannot be attributed to the arrival of news is calculated as $\frac{var\left(\Delta p_t^{AMS} \mid N_t=0\right) \times [Obs(N_t=0)+Obs(N_t=1)]}{var\left(\Delta p_t^{AMS} \mid N_t=1\right) \times Obs(N_t=1) + var\left(\Delta p_t^{AMS} \mid N_t=0\right) \times Obs(N_t=0)}$.

The equality of variances for news and no-news periods is tested using a Brown-Forsythe (B-F) test ($H_0 : ratio = 0$).

*** Indicates statistical significance at the 1% level.

Table 3: Volatility in LND - days with/without news from AMS

		Δp_t^{LND} EIC	BoE	3% Ann
mean	news ($N_t = 1$)	0.013	0.014	0.019
	no-news ($N_t = 0$)	0.066	0.051	0.034
variance	news ($N_t = 1$)	0.629	0.228	0.218
	no-news ($N_t = 0$)	0.630	0.274	0.328
	(B-F statistic)	(0.09)	(1.60)	(5.37)**
skewness	news ($N_t = 1$)	-0.090	0.390	0.214
	no-news ($N_t = 0$)	-0.762	-0.072	0.008
kurtosis	news ($N_t = 1$)	10.49	12.40	9.22
	no-news ($N_t = 0$)	12.94	14.88	12.84
% zero	news ($N_t = 1$)	17.16	15.46	23.42
	no-news ($N_t = 0$)	16.95	18.27	20.73
Obs	news ($N_t = 1$)	746	731	854
	no-news ($N_t = 0$)	590	613	685

Descriptive statistics of London returns over 2 or 3 day periods (denoted t) with or without news from Amsterdam ($N_t = 1$ or $N_t = 0$).
Periods: Sept. 1771 - Dec. 1777 and Sept. 1783 - Mar. 1787.
The equality of variances for news and no-news periods is tested using a Brown-Forsythe (B-F) test ($H_0 : ratio = 0$).
** denotes statistical significance at the 5% level

Table 4: Bad weather samples

		$var\left(\Delta p_t^{AMS}\right)$					
		EIC	SSC	BoE	3% Ann	4% Ann	Obs.
Bad weather sample A	good weather	0.278	0.193	0.151	0.223	0.171	396
	bad weather	0.276	0.203	0.086	0.183	0.209	85
	B-F test	0.00	0.01	0.85	0.14	0.72	
	(p-value)	(0.948)	(0.917)	(0.357)	(0.704)	(0.395)	
Bad weather sample B	good weather	0.295	0.207	0.154	0.220	0.204	337
	bad weather	0.237	0.173	0.105	0.205	0.112	145
	B-F test	0.04	0.12	1.16	0.08	2.21	
	(p-value)	(0.851)	(0.732)	(0.282)	(0.778)	(0.138)	
Bad weather sample C	good weather	0.292	0.201	0.146	0.219	0.194	393
	bad weather	0.216	0.176	0.111	0.195	0.100	89
	B-F test	0.68	0.47	0.51	0.02	0.59	
	(p-value)	(0.410)	(0.494)	(0.478)	(0.896)	(0.444)	

Variances of security returns in Amsterdam. Returns calculated over 2 or 3 day periods (denoted t). No-news observations only.
The sample is split in good and bad weather observations according to three different weather classifications:
- A: arrival of news during period t predicted according to sailing schedule, however no arrival of news.
- B: wind constantly blowing from the east during period t.
- C: for all days of period t at least 2 of the 2 or 3 daily wind observations in the no-go zone.

Periods: Sept. 1771 - Dec. 1777 and Sept. 1783 - Mar. 1787.
The equality of variances for good and bad weather observations is tested using a Brown-Forsythe (B-F) test ($H_0 : ratio = 0$).

Table 5: Momentum and reversals

		Δp_t^{AMS} EIC	BoE	3% Ann.	Obs.
Eqn. (1): $N_t = 1$	$\Delta p_{t-1}^{AMS,news}$ (α_1)	0.052	-0.099	-0.132	
		(0.055)	(0.051)*	(0.051)***	
	$\Delta \widetilde{p}_{t-1}^{LND}$ (α_2)	0.023	0.060	0.100	
		(0.053)	(0.052)	(0.071)	
	Constant (α_0)	0.008	0.028	0.029	
		(0.027)	(0.016)*	(0.020)	
Eqn. (2): $N_t = 0$	$\Delta p_{t-1}^{AMS,no-news}$ (β_1)	-0.123	-0.051	-0.263	
		(0.067)*	(0.055)	(0.074)***	
	Constant (β_0)	0.096	0.039	0.054	
		(0.033)***	(0.020)**	(0.027)**	
	N	1147	1148	1148	
$var\left(\Delta p_t^{AMS} \mid N_t = 1\right)$		0.710	0.218	0.386	678
$var\left(\Delta \widehat{p}_t^{AMS} \mid N_t = 0\right)$		0.279	0.141	0.224	482
B-F test		42.0***	21.2***	16.4***	
$\frac{var\left(\Delta \widehat{p}_t^{AMS} \mid N_t=0\right)}{var\left(\Delta p_t^{AMS} \mid N_t=1\right)}$		0.393	0.647	0.580	
fraction of total $var\left(\Delta p_t^{AMS}\right)$ unexplained by news		0.526	0.758	0.703	

Seemingly unrelated estimates (SUEST) of the following two equations

$$(1)\ \Delta p_t^{AMS} = \alpha_0 + \alpha_1 \Delta p_{t-1}^{AMS,news} + \alpha_2 \Delta \widetilde{p}_{t-1}^{LND} + \varepsilon_t \text{ if } N_{t-1} = 1$$

$$(2)\ \Delta p_t^{AMS} = \beta_0 + \beta_1 \Delta p_{t-1}^{AMS,no-news} + \varepsilon_t \text{ if } N_{t-1} = 0$$

$N_{t-1} \in \{0, 1\}$ indicates whether news arrived in period $t-1$. $\Delta p_{t-1}^{AMS,news}$ and $\Delta p_{t-1}^{AMS,no-news}$ are the Amsterdam news or no-news returns for this period $t-1$.
$\Delta \widetilde{p}_{t-1}^{LND}$ is the London news return observed in $t-1$ if $N_{t-1} = 1$.
α_1 and β_1 measure reversals, α_2 should pick up momentum.
$var\left(\Delta \widehat{p}_t^{AMS} \mid N_t = 0\right)$ measures the variance of Amsterdam no-news returns adjusted for momentum.
A Brown-Forsythe test is presented on the equality of variances of adjusted no-news and non-adjusted news returns.
Robust standard errors reported in parantheses.
***,**,* indicates statistical significance at the 1, 5, and 10% level respectively.

Table 6: Predictive regressions - EIC

	Panel (1): Future Amsterdam EIC returns					
	2/3 days	4/5 days	1 week	2 weeks	3 weeks	4 weeks
Current Amsterdam EIC	0.012	0.014	0.001	0.057	0.066	0.111
returns (2/3 days)	(0.034)	(0.051)	(0.056)	(0.072)	(0.093)	(0.105)
Constant	0.032	0.064	0.095	0.179	0.263	0.349
	(0.018)*	(0.026)**	(0.032)***	(0.046)***	(0.058)***	(0.069)***
N	1536	1530	1524	1506	1488	1471
Adj. R^2	0.00	0.00	0.00	0.00	0.00	0.00
	Panel (2): Future Amsterdam EIC returns					
	2/3 days	4/5 days	1 week	2 weeks	3 weeks	4 weeks
London news EIC	0.043	0.028	0.077	0.077	0.087	0.195
returns (3/4 days)	(0.043)	(0.060)	(0.060)	(0.077)	(0.104)	(0.115)
Constant	-0.007	0.011	0.068	0.131	0.159	0.214
	(0.028)	(0.038)	(0.048)	(0.067)	(0.087)	(0.102)
N	734	733	731	726	719	717
Adj. R^2	0.00	0.00	0.00	0.00	0.00	0.00
	Panel (3): Future London EIC returns					
	2/3 days	4/5 days	1 week	2 weeks	3 weeks	4 weeks
Current London EIC	0.020	-0.011	0.025	0.042	0.063	0.146
returns (2/3 days)	(0.046)	(0.062)	(0.081)	(0.082)	(0.099)	(0.104)
Constant	0.027	0.042	0.053	0.106	0.157	0.199
	(0.023)	(0.032)	(0.039)	(0.055)*	(0.067)**	(0.077)***
N	1167	1302	1322	1335	1336	1336
Adj. R^2	0.00	0.00	0.00	0.00	0.00	0.00

This table tests whether London news returns on EIC stock can (negatively) predict future EIC returns in Amsterdam over future periods (panel 2). London news returns are defined as the London returns between the departure of two subsequent packet boats. Future periods in Amsterdam over which returns are calculated start after the arrival of a packet and run between 2/3 days and 4 weeks. As a comparison, panel (1) and panel (2) test whether own-city 2 or 3 day returns returns (Mon-Wed, Wed-Fri, Fri-Mon) in Amsterdam and London can (negatively) predict future returns.
Robust, bootstrapped (1000 reps.) standard errors are presented in parentheses.
***,**,* denotes significance at the 10, 5, 1% level respectively.

Table 7: Simple structural model - GMM estimates

Parameters	EIC	BoE	3% Ann.
$\sigma^2_{\widetilde{\eta}}$	0.377	0.101	0.158
	(0.092)***	(0.020)***	(0.036)***
$\lambda_1\sigma^2_{\varepsilon}$	0.287	0.043	0.050
	(0.068)***	(0.015)***	(0.033)
$\left(\widehat{\lambda}_1 - \lambda_1 + \widehat{\lambda}_2\right)\sigma^2_{\varepsilon}$	0.158	0.106	0.095
	(0.042)***	(0.041)***	(0.052)*
$\sigma^2_{w_1}$	0.035	0.062	0.172
	(0.052)	(0.017)***	(0.058)***
$\sigma^2_{w_2}$	0.239	0.126	0.237
	(0.056)***	(0.034)***	(0.059)***
Z-test $\sigma^2_{w_1} = \sigma^2_{w_2}$	3.58	2.13	1.13
p-value	(0.000)***	(0.033)**	(0.260)

Iterative GMM estimates of moment equations:

$cov\left(\Delta p^{AMS}_{t,1}, \Delta\widetilde{p}^{LND}_{t-1}\right) = \sigma^2_{\widetilde{\eta}}$

$cov\left(\Delta p^{AMS}_{t,1}, \Delta\widetilde{p}^{LND}_{t}\right) = \lambda_1\sigma^2_{\varepsilon}$

$cov\left(\Delta p^{AMS}_{t,2}, \Delta\widetilde{p}^{LND}_{t}\right) = \left(\widehat{\lambda}_1 - \lambda_1 + \widehat{\lambda}_2\right)\sigma^2_{\varepsilon}$

$var\left(\Delta p^{AMS}_{t,1}\right) = \sigma^2_{\widetilde{\eta}} + \lambda_1\sigma^2_{\varepsilon} + \sigma^2_{w_1}$

$var\left(\Delta p^{AMS}_{t,2}\right) = \left(\widehat{\lambda}_1 - \lambda_1 + \widehat{\lambda}_2\right)\sigma^2_{\varepsilon} + \sigma^2_{w_2}$

This system of equations uses the covariance of London and Amsterdam returns to estimate what fraction of the overall return variance can be attributed to news and what fraction is left unexplained. The weighting matrix and standard errors (in parantheses) are heteroskedasticity- and autocorrellation-consistent (using a Newey-West kernel with optimal number of lags).

***,**,* denotes significance at the 1, 5 and 10% level.

Table 8: Variance decomposition - simple structural model

	EIC	BoE	3% Ann.
$var\left(\Delta p^{AMS}_{t,1}\right)$	0.699	0.207	0.380
public: $var\left(\Delta p^{AMS}_{t,1} \mid \varepsilon, w_1\right)$	53.9%	48.8%	41.6%
private: $var\left(\Delta p^{AMS}_{t,1} \mid \widehat{\eta}, w_1\right)$	41.1%	20.8%	13.2%
unexplained:	5.0%	30.4%	45.3%
$var\left(\Delta p^{AMS}_{t,2}\right)$	0.398	0.233	0.332
private: $var\left(\Delta p^{AMS}_{t,2} \mid w_2\right)$	39.7%	45.5%	28.6%
total public:	40.6%	29.6%	27.7%
total private:	40.7%	30.5%	18.3%
total unexplained:	18.7%	39.9%	54.0%

Variance decompositions. The fractions of the total return variance that cannot be attributed to the incorporation of information is calculated as:

$$\frac{\sigma^2_{w_1} \times N(\Delta p^{AMS}_{t,1}) + \sigma^2_{w2} \times N(\Delta p^{AMS}_{t,2})}{var\left(\Delta p^{AMS}_{t,1}\right) \times N(\Delta p^{AMS}_{t,1}) + var\left(\Delta p^{AMS}_{t,2}\right) \times N(\Delta p^{AMS}_{t,2})}$$

Source: table 7