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Price Discovery across the Rhine

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Abstract
We study opening prices for German and French stocks traded simultaneously in Frankfurt and Paris. In our model investors and traders based in the same country as the firm have better information on its value than foreign traders. Our theory implies that prices set on the domestic market differ from (and are more informationally efficient than) prices set on the foreign market. Empirically, we find significant price discrepancies between home and foreign prices, consistent with lack of integration of international financial markets. For German stocks, home prices are found to be informationally more efficient than foreign prices. The informational efficiency of French stock prices is comparable in the two markets when Frankfurt traders can observe Paris preopening prices before the opening.

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1 Introduction

Perfect financial markets should be fully internationally integrated. All securities should follow the same pricing relation, and especially the law of one price should hold: prices set simultaneousy for the same asset should be the same in different countries.

Market imperfections can lead to international financial markets fragmentation, however. One of the most striking evidence of fragmentation is the equity home bias. A strong body of literature has analyzed how this phenomenon reflects information asymmetries between investors from different countries.

In their theoretical analyses of the home bias, Gehrig (1993) and Brennan and Cao (1997) underscore the informational, linguistic and cultural heterogeneities corresponding with different nationalities. They analyse the market for the stocks of companies based in different countries on which domestic investors have private information. Gehrig (1993) shows investors from one country bias their portfolio holdings towards the shares of that country, reflecting their informational advantage for these shares. Brennan and Cao (1997) show that investors of one country react to the information content of the returns of stocks from the other countries.

In line with these theoretical analyses, there is a strong body of empirical evidence consistent with the view that information asymmetries affect portfolio holdings and investment flows across countries. For example Tesar and Werner (1995) show that of the limited foreign stock holdings by US investors a disproportionate fraction is invested in Canada, possibly because information asymmetries between Canada and the US are limited.[1] Portes and Rey (1999) find that cross border equity trading flows between two countries are increasing in the volume of telephone call traffic between these countries, which arguably is a measure of information dissemination. Hau (1999) finds that traders located outside Germany, in non–German speaking cities earn lower proprietary trading profits on the Frankfurt stock exchange, which points at an information advantage due to corporate headquarters geographic and cultural proximity.[2]

[1] See also Kang and Stulz (1994) and Shukla and Inwegen (1995).

[2] Grinblatt and Keloharju (1999) show that, even within a country, cultural and linguistic distance can affect investment patterns. Indeed, they find that Finnish households

While these papers study portfolio holdings, trading volume and trading profits, the present paper focuses on the consequences of cross–country information asymmetries on stock prices at the microstructure level. Indeed, the impact of international information asymmetries on prices is likely to be relatively more apparent at this level. We focus on the following issues: When stocks are traded in several countries, are they priced differently in their home market and in the foreign market? How does information flow between the different market places? Are stocks priced more efficiently on their home market?

Froot and Dabora (1999) document differences between the prices of twin stocks traded in different countries. Werner and Kleidon (1996) and Hupperets and Menkveld (2002) analyse European stocks traded in the US as ADRs. Their findings are consistent with the view that US investors contribute different information to price discovery than European investors.

The present paper complements this literature by studying another market setting, namely opening prices of French and German stocks in Frankfurt and Paris. This setting offers a natural experiment by isolating the consequences of international information asymmetries from the impact of other factors:

- The very same stocks, e.g., Allianz or Peugeot, are traded on the two markets. This differs from the cases analysed by Froot and Dabora (1999) or Werner and Kleidon (1996) and Hupperets and Menkveld (2002). Twin stocks are actually different, for a number of institutional reasons. ADRs also differ somewhat from the original stocks on which they are based, and, as noted by Werner and Kleidon (1996) conversion is not costless.

- The Frankfurt and Paris markets operate in the same currency, the Euro, so that international differences cannot be driven by foreign exchange risk.

- Price discovery and uncertainty are particularly important at the opening of the market. Hence it is natural to consider this phase of the trading process to study the consequences of potential information asymmetries. Focusing on the opening offers an additional advantage, as it enables us to avoid the nonsynchronicity problems often encountered by times series analyses of price discovery in different markets.

invest more in firms which communicate in their own language, i.e. Finnish or Swedish.

Since September 1999, opening prices in Paris and Frankfurt are set simultaneously, at precisely 9:00 a.m. Central European Time. Thus, we compare prices set simultaneously for the same shares in two different markets.

- For cross listed stocks, the relative liquidity of the Latin American or Canadian markets and the US market is likely to reflect the sheer size and power of attraction of the US market, associated with the large US investors base. In contrast, the French and German investor bases and market sizes are comparable. This offers an additional opportunity to reason ceteris paribus. Note further that the capitalisations of the French and German stocks we study are comparable.

- Finally, the Frankfurt and Paris markets use similar trading mechanisms to set the opening price. In both markets, this price is set in an opening call auction, where limit and market orders to buy and sell are aggregated to form demand and supply curves. This results in a uniform price, set to maximize trading volume.

To provide a framework within which to study these issues, we develop a simple theoretical model nesting the null hypothesis of international financial markets integration and the alternative hypothesis, that markets are internationally segmented. In the former case, there are no informational asymmetries across countries. In the latter, investors based in the same country as a given firm are assumed to be better informed about its value than foreign traders. While this hypothesis is similar to those posited by Gehrig (1993) and Brennan and Cao (1997), the focus of our model differs from theirs: They study how *several securities* are traded in one market by traders from different countries. We model how one security is traded in *several markets* located in different countries. This is because our focus is not on portfolio allocation between stocks from different countries, but on how the price of the same security can differ across markets in different countries.

In the private information scenario we consider, smart investors intervene in the foreign market to exploit their superior information. Since these trades reveal some information, they contribute to integrating the home and foreign markets. As the smart investors are strategic, however, and as some of the trading reflects non–informational motivations, private information is not fully revealed. In equilibrium, when all investors have the same information, prices are aligned in the two markets, while, with information

asymmetry, prices differ across the home and foreign market, and their informational content is greater on the former than on the latter. Note that the corresponding discrepancy between domestic and foreign prices does not imply that arbitrage opportunities are left unexploited in the market. All agents in our model are rational, and the strategic informed agent deliberately allows for this price discrepancy, which reflects his optimal strategy.

To confront this analysis to the data, and test the null hypothessis that financial markets are internationally integrated, we collected opening and closing prices in Paris and Frankfurt between July 1998 and January 2001.

In contrast with the null hypothesis we find significant differences between opening prices for French and German companies established simultaneously in Frankfurt and Paris. We also find that, for German stocks, the information content of the home opening price is greater than its foreign price counterpart. This is consistent with the view that German traders have better information about the value of their domestic stocks, than French traders.

We find similar results for French stocks during the period before September 1999 when Paris opened after Frankfurt. After September 1999, the two markets open simultaneously, and the informational content of French stocks prices is not significantly different in Frankfurt and Paris. We conjecture that this reflects the ability of traders based in Frankfurt to observe the rich flow of price discovery information disseminated by the Paris Bourse during the preopening period. (Note that the Frankfurt stock exchange does not engage in such information dissemination.) This is in line with the finding by Pagano and Roëll (1990), that, before the opening of the French market, spreads quoted in London (on SEAQ international) are particularly wide, while after price discovery has been achieved in Paris, these spreads become tighter.

The structure of the paper is the following: In the next section we present our theoretical model. In Section 3 we describe the institutional environment. In Section 4, we present our data set. The empirical analysis is in Section 5. Section 6 offers a brief conclusion and sketches the policy implications of our analysis for the international integration of bourses.

2 Theoretical analysis

Without market imperfections, and in particular if there are no information asymmetries across countries, theory predicts that financial markets should

be internationally integrated, and all securities should follow the same pricing relation.[3] In particular the law of one price should hold, so that the price quoted for the same asset, at the same point in time, should be the same in markets based in different countries. This is our null hypothesis (H0).

On the other hand, recent research has argued that information sets can differ across countries. As put by Solnik (1996, pages 143 and 144), for example:

> "French investors might have a comparative advantage in buying French shares; they might have better and quicker access to company information."

Better access to company information can be due to interaction with the managers of the companies. It may also reflect better ability to interpret this data, due better understanding of the institutional, social and business context within which the firm operates and presents information about itself. To quote Solnik (1996, page 116):

> "Investors are often unfamiliar with foreign cultures and markets. They feel uneasy about the way business is done in other countries: the trading procedures, the way reports are presented, different languges, different time zones, and so on."

Kang and Stulz (1994), Tesar and Werner (1995), and Portes and Rey (1999) offer empirical evidence consistent with the view that the home bias reflects information asymmmetries across countries. Also consistent with the presence of such asymmetries, Hau (1999) finds empirically that in Frankfurt the trades conducted by German speaking investors are more profitablle than the trades of the foreigners. While these papers offer evidence on the consequences of information asymmetries on holdings, or trading profits, in the present paper we study their consequences on prices.

In line with these remarks, our alternative hypothesis (H1) is that because investors based in different countries have different information sets, financial markets are fragmented.

With fragmented markets, however, smart investors are likely to engage in arbitrage, aimed at exploiting international price discrepancies. Such strategies, in turn, can be expected to drive international markets closer to

[3] For a discussion of international financial integration or fragmentation, see, e.g., Solnik (1996), or Dumas (1994).

integration. To provide a framework wihin which to study these issues, we develop a theoretical model based on the assumption that investors located based in one country have better information about domestic stocks than foreign traders.

Consider the stock issued by firm j, which can be traded on two markets: the domestic exchange, located in the same country as firm j, and the foreign market located in another country. In each of the two markets, competitive risk averse liquidity suppliers place limit orders to serve market orders. The latter are placed by a strategic agent trading both for informational and risk sharing motives.

The large strategic trader is located in the same country as firm j. His information about this firm is similar to that of the traders operating in that country, and better than the information of the traders based in the other country, and operating on the foreign market for this stock. More precisely, we decompose the fundamental value of the stock, v, as follows:

$$v = \mu + s + \epsilon.$$

where:

- μ is the a priori mean of the value,
- s is an informational signal, which is observed only by the local traders on the domestic market, i.e., the liquidity suppliers operating on this market and the strategic informed investor,
- ϵ is a residual noise term, which no one can observe. Denote σ_ϵ^2 its variance.

Our assumption that the information sets of the large traders and the liquidity suppliers in the domestic market are the same is made for simplicity. We have also computed the equilibrium corresponding to the case where the strategic investor has an informational edge over the domestic market liquidity suppliers. Although considerably more complicated, the equilibrium has similar qualitative features as those of the much simpler equilibrium presented here.

For simplicity, we assume that all random variables have a priori means equal to 0 and are jointly normal and independent, and that all agents in the model have CARA utilities, with parameter γ. In this context we investigate

linear equilibria (as in Kyle (1989)), where the price function in the domestic market is:

$$P_d = M_d + \lambda_d q_d,$$

where M_d reflects the information set of the domestic traders and investors, λ_d is a constant, and q_d is the market order placed by the strategic agent on that market. Similarly, the price function in the foreign market is:

$$P_f = M_f + \lambda_f q_f,$$

where M_f and λ_f are constants, and q_f is the market order placed by the strategic agent on the foreign market.

The program to be solved by the strategic informed agent is:

$$Max_{\{q_d,q_f\}} EU((J + q_f + q_d)v - P_f q_f - P_d q_d + C|s, J),$$

where C is the initial cash endowment of this agent, and J her initial endowment in stocks. J is privately known to the strategic informed investor. From the point of the liquidity suppliers, it is a random variable. For simplicity we assume its mean is zero, and it is independently jointly normally distributed with the other random variables present in the model.

The first order condition, relative to q_d is:

$$q_d = \frac{\theta - P_d - \gamma\sigma_\epsilon^2 q_f}{\gamma\sigma_\epsilon^2 + \lambda_d},$$

where:

$$\theta = \mu + s - \gamma\sigma_\epsilon^2 J.$$

θ is equal to the conditional expectation of the fundamental value of the stock for the large trader $(\mu + s)$ minus a risk premium equal to her risk aversion coefficient (γ), multiplied by the residual variance of the value, and her initial endowment in the stock. It measures the valuation of the stock by the strategic agent.[4]

This first order condition is intuitive: the amount purchased by the informed agent in the domestic market is increasing the difference between her valuation and the price, minus her exposure to the stock risk due to her trade in the other market. This amount is decreasing in her sensitivity to

[4]This blend of informational ad risk sharing motivations to trade is in the same spirit as in Glosten (1989) and Biais, Martimort and Rochet (2000).

the risk of the stock ($\gamma\sigma_\epsilon^2$) and her price impact on the domestic market (λ_d).

Similarly, the first order condition of the informed agent relative to q_f is:

$$q_f = \frac{\theta - P_f - \gamma\sigma_\epsilon^2 q_d}{\gamma\sigma_\epsilon^2 + \lambda_f}.$$

The two first order conditions of the informed agent shows how her strategy reflects her rational expectations of the prices prevailing in the two markets. When she expects a discrepancy between the prices prevailing in the two markets, the informed agent strategically exploits it by conducting arbitrage trades. As stated in the propositions below, her optimal arbitrage strategy does not drive the price discrepancy to zero, however. It is optimal for the informed agent to restrain the size of her trades, to maintain a wedge between the domestic and foreign price, and correspondingly optimize her trading profits.

The program of the competitive liquidity suppliers in the domestic market is:

$$Max_{q_d} EU((P_d - v)q_d|s),$$

while that of the competitive liquidity suppliers in the foreign market is:

$$Max_{q_f} EU((P_f - v)q_f|H_f).$$

The difference between the two programs is that the information set of the foreign liquidity suppliers (H_f) is less precise than that of the domestic liquidity suppliers, which includes the private signal (s).

Denote:

$$\delta = \frac{V(s)}{V(s) + (\gamma\sigma_\epsilon^2)^2(\frac{2}{3})V(J)}.$$

δ is a measure of the information content of the order flow, as it is increasing in the informativeness of the insider signal, and decreasing in the non–informational component of the trade. For example, $\delta = 0$ corresponds to the case where there is no private information.

If $\delta < \frac{1}{2}$, i.e., the information content of the order flow is limited, there exists a (unique) linear equilibrium characterized in the following proposition.

Proposition 1 *If $\delta < \frac{1}{2}$, there exists a unique linear equilibrium:*

$$P_d = M_d + \lambda_d q_d, P_f = M_f + \lambda_f q_f,$$

where: $M_d = \mu + s, \lambda_d = \gamma\sigma_\epsilon^2$, and:

$$M_f = \mu, \lambda_f = \gamma[\sigma_\epsilon^2 \frac{1-\delta/3}{1-2\delta} + Var(v)\frac{1-\delta}{1-2\delta}].$$

On the domestic exchange, the impact of trades reflects only the limited risk–bearing capacity of the market makers, i.e., the effective spreads only reflects inventory consideration. On the foreign market, the impact of trades also reflects their informational content. Correspondingly, the effective spread has an additional component due to adverse selection. The following propositions spell out further the properties of the equilibrium. By comparing λ_d and λ_f one directly obtains the first property:

Proposition 2 *In equilibrium defined in Proposition 1, the market impact of trades is greater on the foreign market than on the domestic market, i.e., $\lambda_f > \lambda_d$.*

The market impact of trades is greater on the foreign market, or, to put it differently, that market is less deep. This is because, as mentioned above, in addition to the inventory component of the effective spread, there is an adverse selection component. Substituting the equilibrium trades into the equilibrium price functions, the next property is obtained:

Proposition 3 *In the equilibrium defined in Proposition 1, the prices on the two markets can be written as follows:*

$$P_d = \mu + \beta_d s + \kappa J,$$

$$P_f = \mu + \beta_f s + \kappa J,$$

where

$$\beta_d = \frac{6\lambda_f + \gamma\sigma_\epsilon^2}{6\lambda_f + 2\gamma\sigma_\epsilon^2},$$

$$\beta_f = \frac{3\lambda_f}{6\lambda_f + 2\gamma\sigma_\epsilon^2},$$

and

$$\kappa = \frac{2\lambda_f\gamma\sigma_\epsilon^2}{6\lambda_f + 2\gamma\sigma_\epsilon^2}.$$

The transient component (κJ) of the price is the same on the two markets. This corresponds to the fact that, to share risk, the informed agent hedges her endowment shock by splitting it similarly across the two markets. In contrast, reflecting the better information of the home traders, the informational component of the price is greater on the domestic market than on the foreign market, i.e., $\beta_d > \beta_f$.

Building on the proposition above, the following corollary directly obtains:

Corollary:
Under information asymmetry (when $\delta > 0$), stock prices set simultaneously for the same stock are different in the domestic and the foreign market, i.e., markets are internationally fragmented. In contrast, if $\delta = 0$, the price is the same in the two markets, i.e., markets are perfectly internationally integrated (consistent with H0).

The price discrepancy underscored in the corollary concerns equilibrium stock prices, reflecting the intervention of informed arbitrageurs, and the respective liquidity of the domestic and foreign markets.

When $\delta = 0$, while foreign and domestic prices are the same, trades still have an impact on prices, i.e., markets are not perfectly liquid, since there are inventory effects. Without adverse selection, however, the price impact of trades is the same in the two markets, which have identical liquidity. Correspondingly, the observation that liquidity differs in the two markets, is consistent with the hypothesis that there are international information asymmetries.

To study further the informational content of prices set in the domestic and foreign market, note that the informational efficiency of market i ($i \in \{d, f\}$), is decreasing in the variance of the difference between the fundamental value and the price set on that market:

$$Var(v - p_i).$$

Using the results spelled out above, we obtain the following property:

Proposition 4 *The informational efficiency of the domestic market is greater than that of the foreign market, i.e.:*

$$Var(v - p_d) < Var(v - p_f).$$

The proposition naturally reflects the fact that liquidity suppliers on the domestic market are better informed about the value of the security than those operating in the foreign market.

A complementary way to approach the different informational efficiency of the domestic and foreign stock prices is to study, in a times series spirit, if one leads the other. If the informational content of the domestic price is greater than that of the foreign price, when the former is above the latter, this predicts that the stock is undervalued on the foreign market. To establish this point consider the covariance between the difference between the two prices: $p_d - p_f$, and the difference between the fundamental value and the foreign market price: $v - p_f$. Substituting the prices from Proposition 3, this covariance is:

$$cov(p_d - p_f, v - p_f) = (\beta_d - \beta_f)(1 - \beta_f)Var(s),$$

which is positive because: $\beta_d > \beta_f$ and $1 > \beta_f$. This is stated in the next proposition.

Proposition 5 *The difference between the home and foreign market prices is positively correlated with the difference between the value of the stock and the foreign price, i.e.,* $cov(p_d - p_f, v - p_f) > 0$.

The proposition implies that when the foreign price is below the domestic price, it is likely to catch up, by adusting upward.

3 Institutional context

European stock markets offer an appropriate laboratory to study whether there are pricing discrepancies across countries, as suggested by the above theoretical analysis.

Cultural and linguistic barriers and differences are at play in Europe. Traders and investors one country are better able than foreign traders to gather useful information from direct contacts with domestic firm managers and government officials. Domestic traders are better able than foreign traders to interpret accounting as well as less formalized information stemming from domestic firms.

The French and German stock exchange operate in the same currency, the Euro. Consequently, if the data is suggestive of international financial market fragmentation, it cannot be due to exchange rate risk.

Over the recent years, the French and German stock exchanges have been competing to attract order flow. Barriers to cross borders trading and investing have been reduced. The French and German stock markets have converged towards a relatively unified market model, revolving around electronic limit order books. This has facilitated the parallel trading of the major European stocks on these two exchanges.[5]

The Paris Bourse is an electronic pure limit order market (its system is called NSC).[6] During the preopening period, investors can place, revise and cancel limit orders in the electronic book, and tentative market clearing prices are computed and disseminated in real time. Until September 20th, 1999, the preopening period lasted from 8:30 to 10:00 C.E.T. Since September 1999, it lasts from 7:45 to 9:00 C.E.T. At the end of the preopening period, the opening price is set in a uniform price call auction. Then, until 5:00 there is a continuous market where investors can dynamically place limit or market orders in the book and where trades take place as soon as a bid and an offer cross.[7] As shown empirically by Declercq (2000), brokers and financial intermediaries play an active role in supplying liquidity on the Paris market, by placing limit orders not unlike market makers.

In Germany, stocks are traded on the floors of the Frankfurt Stock Exchange and the Regional Exchanges. The microstructure of these exchanges is comparable to that of the NYSE. Investors can place market and limit orders in the book. The specialist (Makler) manages the order book, post quotes, participates to trades and maintains the market. At the opening, similarly to the NYSE, traders submit limit or market orders, the Makler announces an indicative price, traders can revise orders, finally the Makler places his own orders in the book, and this determines the opening price. Before September 1999, the opening of the Frankfurt Stock Exchange took place at 8 :30 C.E.T. Since September 1999 it occurs at 9:00 C.E.T. On average, 12.12 % of the total trading volume in the Frankfurt Stock Exchange takes place at the opening call auction (see Kehr, Krahnen, Theissen, 1998). In parallel with the floor there is an electronic limit order book XETRA (eX-

[5] Dermine (1999) and Biais (1999) discuss the integration of European stock markets. Demarchi and Foucault (1998), and Deutsche Börse (1998) offer useful information on the organization of the markets.

[6] The trading system used in the Paris Bourse since 1994: NSC, is similar to the previous one: CAC, except that it relies on a more powerful computer system. The capacity of order flow treatment has been increased from 30 to 60 orders per second.

[7] For an empirical analysis of the preopening period, see Biais, Hillion and Spatt (1999). For an analysis of the continuous market, see Biais, Hillion and Spatt (1995).

change Electronic TRAding). About 25 % of the trading volume of DAX stocks in Germany are on the floor of the Frankfurt Stock Exchange while 75 % are on Xetra (see Demarchi and Foucault, 1998). The workings of XETRA are comparable to those of NSC. Yet, in addition to other investors, market makers (Betreuer) post quotes on this market. The Betreuer must participate in the opening. XETRA opens at the same time as the Frankfort floor.

The three main differences between the Paris and Frankfurt stock exchanges are the following: First, until September 1999 (but not after), Frankfurt opened before Paris. Second, the preopening period is much more developed in Paris than in Frankfurt. In Xetra there is a short preopening period, with little information dissemination. On the Frankfurt floor market there is no formalized preopening period and no systematic price discovery information dissemination outside the floor. In contrast, in Paris, there is a long preopening period, attracting vast participation, and generating widely disseminated preopening prices, with significant information content (see Biais, Hillion and Spatt, 1999). Finally, while Paris is a pure limit order book, in Frankfurt, there is a specialist, actively maintaining the market, and playing an important role in the determination of the opening price.

4 Data

We have collected (on Datastream) opening and closing prices for 9 German firms and 19 French firms (listed in Table 1) for three periods. The first period, from July 1st 1998 to July 1st 1999, is when Frankfurt opened before Paris. The second period, from September 20th 1999 to January 17th 2000, is just after the harmonization of the opening times. During the third period, from September 1, 2000 to January 10, 2001, Paris and Frankfurt also open simultaneously. By differentiating periods 2 and 3, we control for the effect of potential delays in the adjustment of the market participants to the new opening times. The French and German firms included in our sample are those for which opening and closing prices are available in the Datastream database throughout the whole sample period. They represent about two thirds of the capitalization of the DAX and the CAC40. This suggests that stocks representing a large fraction of the capitalization of the German and French equity markets are actively traded on the other major European markets.

While opening prices for French and German stocks are available for al-

most trading everyday on the Paris Bourse and the floor of the Frankfurt stock exchange, French stocks are relatively infrequently traded on Xetra. Hence, we focus on the data stemming from the Paris Bourse and the Frankfurt floor. We have checked, however, that opening prices set on the Frankfurt floor market and on Xetra are aligned, for German stocks, as well as for French stocks when quotes are available on Xetra.

5 Empirical analysis

5.1 Differences between opening prices

Using opening prices we can test the empirical implications of Proposition 3, that prices are different in the two markets.[8] To study this point we focus on opening prices. The opening offers a particularly appropriate testing ground for our theory for at least two reasons:

- The opening of the market is crucial for the discovery of the valuation of the asset, since at this point in time, the information and orders arrived since the previous close need to be factored in the price. Correspondingly, asymmetric information problems are likely to be particularly prevalent at this point in time.[9]
- The opening offers an opportunity to conduct a clean comparison of prices set in different markets, without encountering non–synchronicity issues, because, during the second and third period in our sample, the Paris and Frankfurt markets open simultaneously.

For each stock, we estimate the average of the absolute value of the percentage difference between home and foreign opening prices. The stock by stock results are presented graphically in Figures 1, 2 and 3 while averages across stocks are provided in Table 2.

Consistent with Proposition 3, the empirical results point to a non–trivial difference between the home and foreign opening prices. This is consistent with the hypothesis that opening prices in the home and foreign markets

[8] Because we do not have high frequency data on limit orders for the German market, we cannot test the empirical implication of Proposition 2 that depth is greater in the domestic market.

[9] See Amihud and Mendelson, 1987, 1990, Stoll and Whaley, 1990, Biais, Hillion and Spatt, 1999, Madhavan and Penchapagesan, 1999, Kehr, Krahnen and Theissen, 1998, and Medrano and Vives, 1999.

are based on different information sets. The estimates are of the order of magnitude of 1%. This price difference is economically significant, as it is approximately three times larger than the typical bid–ask spread prevailing for the stocks in our sample. It should be emphasized that the discrepancy between the foreign and the domestic price concerns transaction prices rather than simply quoted prices. These opening transaction prices thus reflect the arbitrage trades of investors intervening in the two markets.

The discrepancy between home and foreign prices is large throughout the three periods. Even during the second and third periods, for which prices are set simultaneously in the two markets, there is a wedge between home and foreign prices.

For French stocks the average difference between home and foreign opening prices is greater for the first period (1.27 %) than for the second and third periods (0.86 % and 0.98 % respectively). This is natural as, during the first period, Frankfurt opens before Paris, while during the second and third periods the two markets open simultaneously. Hence, during the second and third periods, Frankfurt traders can use the information revealed during the preopening period in Paris to set the prices of French stock. In contrast, during the first period, Frankfurt traders must value French stocks based on less rich information.

For German stocks, the difference between home and foreign prices remain large during the three periods. For the first period, it could reflect different opening times, not for the two other periods.

While the results in Table 2 and Figures 1, 2 and 3 suggest that there is a marked difference between the Frankfurt and Paris opening prices (consistent with Proposition 3), they do not provide direct evidence to compare the informational contents of the home and foreign markets. We analyze that point in the next subsection.

5.2 Comparing the informational content of the domestic and foreign opening prices

Proposition 4 states that the variance of the difference between the domestic price and the value $Var(v - P_d)$ should be smaller than its foreign counterpart $Var(v - P_f)$. To put this result to a test, we need a proxy for the fundamental value of the security. We choose to use the closing price on the domestic market as such a proxy. While it is likely that this price contains noise in addition to the fundamental value, this does not alter the ranking of the variances defined in Proposition 4, as long as this noise is indepen-

dent from the other variables in the model. To see this denote the noise component in the proxy as ξ, and note that under the assumption that ξ is independent from the random variables s, J, and ϵ:

$$Var(v - p_d) < Var(v - p_f) \Leftrightarrow Var(v + \xi - p_d) < Var(v + \xi - p_f).$$

To mitigate heteroskedasticity, in this comparison of variances, we normalize all prices by the previous domestic market closing price.

Until August 1999, Frankfurt opened one hour before Paris. Hence for that period, we do not study German stocks. If we found a greater variance on the German market it could simply reflect the fact that the French market, opening one hour later, has been able to incorporate the price discovery already achieved that morning in Frankfurt. Note that for French stocks the differences in opening times between Frankfurt and Paris does not raise problems in light of our theoretical analysis. In our model, liquidity suppliers operating on the home market do not have anything to learn from the foreign market, and foreign liquidity suppliers post quotes without observing the foreign price. This matches the case where the foreign market opens before the domestic one as well as the case where they open simultaneously. Consequently the implication from theory is exactly the same in the two case. During the second and third periods (after September 1999) the two markets open simultaneously and we compute the variances for German as well as French stocks.

The results for the first period are graphically represented in Figure 4. For 14 stocks out of 19, the foreign variance is above the home variance, consistent with our model. As reported in Table 3, the average across stocks of the difference between the foreign and home variances is -10^4. Regarding the null hypothesis that the difference is 0, the Student t is equal to 2.07, consistent with the foreign and domestic variances being significantly different.

The results for the second and third periods are graphically represented in Figures 5 and 6.

For German stocks, the foreign variance is greater than the domestic variance in all 9 cases and for both periods, as predicted by our theoretical analysis. As reported in Table 3, the average across stocks of the difference between the home and foreign variances is -2 10^{-4} and -2.8 10^{-4} for the second and third periods respectively. The corresponding t statistics are -5.2 and -5.3, respectively. Hence the hypothesis that the home variance is equal to the foreign variance is rejected.

For French stocks, the magnitude of the difference between the home and the foreign variance is lower, and the home variance is greater than the foreign variance except in 6 cases during the second period, and 4 cases during the third period. The average of the difference is 9.34 10^{-5} for the second period and 4.4 10^{-6} for the third. The corresponding t statistics are 1.68 and 0.11 respectively. Hence, while the foreign variance tends to be somewhat lower, the difference is not statistically significant.

Our results relative to periods two and three suggest that the Frankfurt market does a very good job at pricing French stocks (better indeed than the way the French market prices the German stocks...). Our interpretation is that this is due to the presence of an informative and transparent preopening period in Paris and not in Frankfurt. An alternative interpretation could be that, in Frankfurt, the presence of the Specialist improves price discovery, in particular for French stocks. If that was the main driving force, however, the superior performance of Frankfurt should also be observed for the first period, during which the Specialist is also present. Yet, we find that in that period, Frankfurt prices for French stocks are not very informative and much less efficient than in periods two and three (see Table 3). This suggests that the key ingredient in the quality of Frankfurt prices is the ability of Frankfurt investors to observe preopening prices set in Paris, as in the second and third periods, and unlike in the first one.

Our comparison of variances, and our reliance on Student t statistics are in the same spirit as Amihud and Mendelson (1987 and 1990) and Stoll and Whaley (1990). Ronen (1996) notes that Student tests may not be appropriate because of correlation between the time series of different stocks. In line with her analysis we therefore computed Wald tests, accounting for this correlation. Denote $\Delta = (\Delta_j)_{j=1,...N}$, the vector of the estimated differences between the domestic and foreign variances for the N stocks, T the number of days in the time series, and Σ_Δ the variance covariance matrix of the estimates.The Wald test statistic is:

$$T\Delta^{'}\Sigma_{\Delta}^{-1}\Delta,$$

and asymptotically follows a Chi square distribution with N degrees of freedom. Computing this statistic, we obtain p–values well below .001. Hence the null hypothesis that there is no difference between domestic and foreign variances is rejected.

5.3 Is the foreign price overvalued when it is above the home price?

Proposition 5 states that the difference between the home and foreign market prices is positively correlated with the difference between the value of the stock and the foreign price, i.e., $cov(p_d - p_f, v - p_f) > 0$. To test this implication of our theoretical analysis we have estimated this covariance for each of the stocks in our sample, and for the different periods. The averages across stocks are reported in Table 4, along with t statistics corresponding to the null that the covariance is 0. Consistent with Proposition 5, the average covariances are positive in all cases and statistically significant from 0. That is, when the foreign opening price is below (resp. above) its home counterpart, it is undervalued (resp. overvalued) on average.

Note that the information contained in these covariances is not redundant relative to the information contained in the home and foreign variances presented in the previous subsection. Indeed, by definition:

$$cov(p_d - p_f, v - p_f) = \frac{V(v - p_f) + V(p_f - p_d) - V(v - p_d)}{2}.$$

Hence, the covariance reflects both i) the home and foreign variances and the ii) the variance of the difference between the home and foreign opening prices.

6 Conclusion

In contrast with the null hypothesis that financial markets are internationally integrated, we find significant differences between opening prices for French and German companies established simultaneously in Frankfurt and Paris. This result is all the more striking that it does not reflect non–synchronicity in the data or discrepancies dues to exchange rates (as both markets operate in Euros). Our results are consistent with the hypothesis that financial markets are internationally fragmented due to informational asymmetries. More precisely our findings suggest that traders and investors based in Frankfurt (resp. Paris) have better information about the value of German (resp. French) stocks, resulting in more efficient price discovery in the home market than in the foreign maket. Thus we concur with the conclusion of Pagano, Randl, Roell and Zechner (2001): "Despite the increasing integration of capital markets, geography has not yet become irrelevant to finance."

Our analysis points at the following policy implications. Informational asymmetries correlated with nationality could represent significant barriers to the unification of stock markets, in particular in Europe, in spite of the EMU. Our results also imply that transparent price discovery mechanisms such as the preopening period in the Paris Bourse facilitate international financial markets integration. This raises a problem, however. The widely disseminated preopening tâtonnement mechanism offered by the Paris Bourse improves the efficiency of opening prices set in Paris *and in Frankfurt*. Thus, in some sense the Frankfurt Börse is free–riding on information produced by the Paris Bourse. Such free–riding problems might deter exchanges from disseminating useful price discovery information. In fact, exchange officials in the US have told us that one reason why the NYSE does not offer a transparent and widely disseminated preopening mechanism is because it fears this would help its competitors diverting orders away from the exchange.

Our theoretical model analyzes price formation for a given stock on the home and foreign markets. It would be interesting, in further research to extend this to several stocks. A first step would be to consider two countries, each with a domestic exchange, and to analyze the trades of investors from the two countries, with better information on their home market stock. This could enable one to extend our analysis to the study of portfolio choice, and could help shed light on the links between price discrepancies across nations and portfolio choices puzzles such as the home bias.

Appendix: Proofs

Proof of Proposition 1:

Substituting in $P_i = M_i + \lambda_i q_i, i = f, d$, in the first order condition of the strategic investor yields a system of two equations with unknowns q_f and q_d. Solving this system one obtains the trades in the two markets as a function of the exogenous variables and the parameters of the model:

$$q_d = \frac{(\theta - M_d)2\lambda_f + \gamma\sigma_\epsilon^2(M_f - M_d)}{4\lambda_f\lambda_d + 2\gamma\sigma_\epsilon^2(\lambda_f + \lambda_d)},$$

and:

$$q_f = \frac{(\theta - M_f)2\lambda_d + \gamma\sigma_\epsilon^2(M_d - M_f)}{4\lambda_f\lambda_d + 2\gamma\sigma_\epsilon^2(\lambda_f + \lambda_d)}.$$

The first order condition of the liquidity suppliers in the domestic market yields:

$$P_d = \mu + s + \gamma\sigma_\epsilon^2 q_d.$$

Identifying with the linear conjecture:

$$P_d = M_d + \lambda_d q_d,$$

yields:

$$M_d = \mu + s, \lambda_d = \gamma\sigma_\epsilon^2.$$

The first order condition of the liquidity suppliers in the foreign market is:

$$P_f = E(v|q_f) + \gamma Var(v|q_f)q_f.$$

Anticipating rationally the first order condition of the informed agent, which states that:

$$q_f = \frac{(\theta - M_f)2\lambda_d + \gamma\sigma_\epsilon^2(M_d - M_f)}{4\lambda_f\lambda_d + 2\gamma\sigma_\epsilon^2(\lambda_f + \lambda_d)},$$

the market makers of the foreign market interpret q_f as informationally equivalent to: $\theta + \frac{\gamma\sigma_\epsilon^2}{2\lambda_d}M_d$. Substituting the values of λ_d and, and manipulating M_d, q_f is informationally equivalent, for the market makers of country 2 to:

$$\theta_2 = s + \frac{2}{3}\gamma\sigma_\epsilon^2 J.$$

Hence,

$$E(v|q_f) = E(v|\theta_2),$$

which after some manipulations yields:

$$E(v|q_f) = \mu + \delta\theta_2.$$

Similarly:

$$Var(v|q_f) = Var(v|\theta_2) = Var(v) - \delta Var(s).$$

Hence:

$$P_f = \mu + \delta\theta_2 + \gamma(Var(v) - \delta Var(s))q_f.$$

Rewriting θ_2 in terms of q_f, this yields P_f as a function of q_f. Identifying this function with the linear conjecture, $P_f = M_f + \lambda_f q_f$, the parameters of the price function on the foreign market are obtained:

$$M_f = \mu, \lambda_f = \frac{1-\delta/3}{1-2\delta}(\gamma\sigma_\epsilon^2) + \frac{1-\delta}{1-2\delta}\gamma Var(v).$$

QED

Proof of Proposition 4:

Using Proposition 3, it is easy to show that:

$$Var(v - P_d) < Var(v - P_f) \Leftrightarrow (\beta_d - \beta_f)(\beta_d + \beta_f) < 2(\beta_d - \beta_f).$$

Since $\beta_d > \beta_f$, this is equivalent to:

$$\beta_d + \beta_f < 2.$$

Substituting the values of β_d and β_f, this inequality holds.

QED

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Table 1: The firms in our sample.

German Firms	Adidas-Salomon
	Allianz
	BASF
	Bayer
	Daimler-Chrysler
	Deutsche Bank
	Dresdner Bank
	Siemens
	Volkswagen
French Firms	Accor
	Alcatel
	Aventis
	AXA-UAP
	Canal Plus
	Cap Gemini
	Carrefour
	Danone BSN
	Elf Aquitaine
	France Telecom
	L'Oréal
	LVMH
	Peugeot
	Renault
	St Gobain
	Société Générale
	Suez
	Total
	Vivendi

Table 2
Average absolute value of the percentage difference between the opening prices in Paris and Frankfurt
(The figure in parentheses is the Student t corresponding to the null hypothesis that there is no difference between the current period and the previous one.)

	All stock	French stocks	German stocks
Period 1	1.25%	1.27 %	1.23%
Period 2	0.9%	0.86 % (4.74)	1.04 % (1.35)
Period 3	1.26 %	0.98 % (-0.88)	1.85% (-5.28)

Table 3
Variance(closing price-home opening) - Variance(closing price-foreign opening)

We estimate the difference in variances for each stock (to mitigate heteroskedasticity both opening and closing prices are normalized by the previous close). In the table we report averages and t statistics across stocks. The figure in parentheses is the Student t corresponding to the null that there is no difference between the home and the foreign variance.

	All stock	French stocks	German stocks
Period 1	-10^{-4} (-2.07)	-10^{-4} (-2.07)	n.a
Period 2	$-1.5\ 10^{-6}$ (-0.03)	$9.34\ 10^{-5}$ (1.68)	$-2\ 10^{-4}$ (-5.2)
Period 3	$-8.9\ 10^{-5}$ (-2.17)	$4.4\ 10^{-6}$ (0.11)	$-2.8\ 10^{-4}$(-5.3)

Table 4
Covariance (opening price home market - opening price foreign market, closing price home market - opening price foreign market)

We estimate the covariance for each stock (to mitigate heteroskedasticity both opening and closing prices are normalized by the previous close). In the table we report averages and t statistics across stocks. The figure in parenthesis is the Student t corresponding to the null that the covariance is 0.

	All stock	French stocks	German stocks
Period 1	2^{-4} (6.04)	2^{-4} (6.04)	n.a
Period 2	$8.3\ 10^{-5}$ (4.01)	$2.64\ 10^{-5}$ (2.3)	$2\ 10^{-4}$ (5.7)
Period 3	$2\ 10^{-4}$ (4.1)	$9.4\ 10^{-5}$ (1.8)	$4\ 10^{-4}$(8.6)