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Price Discovery across the Rhine ⋆

BRUNO BIAIS[1] and ISABELLE MARTINEZ[2]
[1]*IDEI, Gremaq and CRG, Toulouse University;* [2]*CRG, Toulouse University*

Abstract. We study opening prices set simultaneously for German and French stocks 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.

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 pieces of evidence on fragmentation is the equity home bias.[1] A large body of literature has documented that 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 frictions arising from cultural heterogeneities corresponding with different nationalities. Gehrig (1993) shows that investors from one country bias their portfolio holdings towards the shares of that country, reflecting their informational advantage for these shares. In the theoretical analysis of Brennan and Cao (1997), foreign investors are less well informed than domestic ones and need to learn from observed returns, which partly reflect the private signals of the local investors.

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[1] See, e.g., Cooper and Kaplanis (1994).

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 amount of foreign stock held by US investors a disproportionate fraction is invested in Canada, possibly because information asymmetries between Canada and the US are limited.[2] 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 the intensity of information flows. Hau (2001) finds that traders located outside Germany, in non-German speaking cities earn lower proprietary trading profits on the Frankfurt stock exchange, which points to an information disadvantage.[3]

While these studies analyse portfolio holdings, trading volume and trading profits, the present paper focuses on the consequences of cross-country information asymmetries for 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?

Some studies have already started to explore these issues. 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.

[2] See also Kang and Stulz (1997) and Shukla and Inwegen (1995).

[3] Grinblatt and Keloharju (2001) show that, even within a country, cultural and linguistic distance can affect investment patterns. Indeed, they find that Finnish households invest more in firms which communicate in their own language, i.e., Finnish or Swedish.

- 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 non-synchronicity problems often encountered by times series analyses of price discovery in different markets. 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 hold other factors constant in the comparison. Note further that the capitalisations of the French and German stocks that 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 for our empirical analysis, 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 that 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 bring this analysis to the data, and test the null hypothesis that financial markets are internationally integrated, we collect opening and closing prices in Paris and Frankfurt between July 1998 and January 2001.

We find economically and statistically significant differences between opening prices for French and German companies established simultaneously in Frankfurt and Paris, and accordingly reject the null hypothesis of perfect integration. 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 do.

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 stock 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 stock exchanges.

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.[4] 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 (H_0).

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.

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

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 to better understanding of the institutional, social and business context within which the firm operates and presents information about itself. To quote Solnik (1996, p. 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 languages, different time zones, and so on.

In line with these remarks, our alternative hypothesis (H_1) is that because investors based in different countries have different information sets, financial markets are fragmented. Even 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 integration.

To provide a framework for our empirical analysis of opening prices, we develop a theoretical model based on the assumption that investors located in one country have better information about domestic stocks than foreign traders.

Consider the stock issued by firm j, which can be traded simultaneously 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. Market and limit orders are aggregated to set the uniform market clearing price at which trades occur in the uniform price auction used to open the market.

Liquidity demand stems from the strategic agent, placing market orders both for informational and risk sharing motives. The assumption that the informed agent is strategic plays an important role in our analysis. If he did not realize he had an impact on prices, he would arbitrage away any difference between the home and foreign market. Because he is strategic, however, he will refrain from doing so. As shown below, he will optimally choose the size of his trades, and the corresponding prices on the two markets, to maximise his expected utility.

The large strategic trader is located in the same country as firm j. He observes the same signal about the value of the firm (s) as the other traders operating in that country. Their information about the value of the firm is better than that of the traders based in the other country, who do not observe the signal s. More precisely, we decompose the fundamental value of the stock, v, as follows:

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

where

- μ is the unconditional mean of the value,
- s is an informative 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 by σ_ϵ^2 its variance.

Our assumption that the large traders and the liquidity suppliers in the domestic market observe the same signal (s) 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.

While both the large strategic trader and the domestic liquidity suppliers observe the signal s, we assume that only the former exploits this informational advantage in the foreign market. While this assumption is made for simplicity, it can be motivated as follows. The strategic informed agent is a large financial institution, with subsidiaries in several countries. It has established efficient links with cross border clearing and settlement networks. Thus, for this investor, the transactions costs of cross-border trades are limited. For simplicity we normalize them to 0. On the other hand, in the limit order market we consider, liquidity supply is provided by a relatively large number of traders and investors, of various sizes. While these investors have established connections with their local exchange and thus minimize clearing and settlement costs in the domestic market, they have no such links with the foreign market. Thus, while they find it attractive to place limit orders in the domestic market, cross-border transactions costs make it unprofitable for them to trade in the foreign market.

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:
footnoteStrategic traders make decisions based on their conjecture on the price function. Rational expectations require that this conjecture be equal to the actual price function. While the linear conjecture is rational, other equilibria might exist. Focusing on linear equilibria thus can be viewed as a selection device.

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

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 viewpoint of the liquidity suppliers, this endowment shock is a random variable. For simplicity we assume that the mean of the endowment shock J is zero and that is independently jointly normally distributed with the other random variables present in the model.

Observing J would not alter the behavior of the domestic liquidity suppliers, since they observe the same informational signal (s) as the strategic informed trader and since they post competitive quotes. In contrast, observing J would matter for the foreign liquidity suppliers. Since they do not observe s, they must infer information about it from the trade of the strategic informed trader on their own market (q_f). However, this trade also reflects the endowment shock of the informed trader. Thus J introduces noise in the signal observed by the foreign traders. Note further that we assume the foreign liquidity suppliers only observe the market order addressed to their own market (q_f) and not the market order addressed to the domestic market (q_d, or equivalently the price set on that market, P_d). This assumption reflects the informational structure of the markets at the opening, when there is no electronic dissemination of preopening price. For example, as there is no electronic dissemination of pre-opening period prices from the German market, and since the two markets open rigorously simultaneously, at the opening French traders do not know the Frankfurt price of German stocks. In the interpretation of our empirical results below, we discuss the consequences of the existence of a transparent pre-opening period in the Paris Bourse for the pricing of French stocks in Frankfurt at the opening.

The first-order condition relative to q_d yields:

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

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.[5]

This first-order condition is intuitive: the amount purchased by the informed agent in the domestic market is increasing in the difference between her valuation and the price, minus her exposure to the risk due to her trade in the other market. This amount is decreasing in her sensitivity to the risk of the stock ($\gamma\sigma_\epsilon^2$) and her price impact on the domestic market (λ_d).

[5] This blend of informational and risk sharing motivations to trade is in the same spirit as in Glosten (1989) and Biais et al. (2000).

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

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

The two first-order conditions of the informed agent show 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. This is similar to the trade-off faced by a monopolist in product markets, who limits the quantity sold to customers to enhance his profits, by maintaining a margin between the selling price and his marginal cost. Similarly, in the present model, the strategic informed agent limits the size of his trade to enhance his profits by maintaining a margin between the home and domestic prices.

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).

It is useful to define:

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

δ is a measure of the information content of the order flow, as it is increasing in the variance of the insider signal ($Var(s)$), and decreasing in the variance of the hedging demand ($Var(J)$). For example, $\delta = 0$ corresponds to the case where the signal of the informed agent has zero variance, and thus has no information content. δ is also small when most of the variance of the order flow arises from the hedging demand, as $Var(J)$ is large relative to $Var(s)$.

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 reflect inventory considerations. 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.

Proposition 1 focuses on the case where information asymmetry is limited, as $\delta < 1/2$. This is in the same spirit as Glosten (1989) where equilibrium is characterized when the informational component of the trade is limited relative to hedging demand. Glosten (1989) discusses how, when this is not the case, liquidity suppliers cannot protect themselves by setting a very steep price schedule, because that would discourage hedging demand as well as information motivated demand.

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 the 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 H_0).

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 compare price discovery on 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:

$$cov(p_d - p_f, v - p_f) = \frac{1 - \beta_f}{2} Var(s),$$

which is positive, since $1 > \beta_f$. 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 p_f is below the domestic price p_d, it is likely to increase, adjusting towards the final value of the stock v.

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 in 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 information about domestic firms.

The French and German stock exchanges 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.[6]

The Paris Bourse is an electronic pure limit order market (its system is called the Nouveau Système de Cotation, NSC).[7] During the preopening period, investors can place, revise and cancel limit orders in the electronic book, and tentative market

[6] Dermine (1999) and Biais (1999) discuss the integration of European stock markets. Demarchi and Foucault (2000), and Deutsche Börse (1998) offer useful information on the organization of the markets.

[7] 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.

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.[8]

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, posts quotes, participates in 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 percent of the total trading volume in the Frankfurt Stock Exchange takes place at the opening call auction (see Kehr, Krahnen, Theissen, 2001). In parallel with the floor there is an electronic limit order book XETRA (eXchange Electronic TRAding). About 25 percent of the trading volume of DAX stocks in Germany are on the floor of the Frankfurt Stock Exchange while 75 percent are on Xetra (see Demarchi and Foucault, 2000). The functioning of XETRA is comparable to that 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.

[8] 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). 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.

4. Data

We collected (on Datastream) opening and closing prices for 9 German firms and 19 French firms (listed in Table I) for three periods. In the first period, from July 1st 1998 to July 1st 1999, Frankfurt opened before Paris. The second period, from September 20th 1999 to January 17th 2000, is just after the harmonization of the opening times. Also, during the third period, from September 1, 2000 to January 10, 2001, Paris and Frankfurt open simultaneously. We treat period 2 and 3 separately, in order to control for the effect of potential delays in the adjustment of the market participants to the new opening times. The stocks in our sample include all the companies for which opening and closing prices are available in the Datastream database throughout the whole sample period and represent about two thirds of the capitalization of the DAX and the CAC40 indices. This indicates that stocks representing a large fraction of the capitalization of the German and French equity markets are actively traded across national borders.

While opening prices for French and German stocks are available for almost every trading day 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 as well as for French stocks when quotes are available on Xetra.

5. Empirical Analysis

5.1. DIFFERENCES BETWEEN OPENING PRICES

We first test the empirical implications of Proposition 3, that prices are different in the two markets.[9] 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 into the price. Correspondingly, asymmetric information problems are likely to be particularly prevalent at this point in time.[10]
- The opening phase 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.

[9] 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.

[10] See Amihud and Mendelson (1987, 1990), Stoll and Whaley (1990), Biais et al. (1999), Madhavan and Penchapagesan (2000), Kehr et al. (2001) and Medrano and Vives (2001).

Table I. Absolute value of the percentage difference between opening prices in Paris and Frankfurt

Nationality	Company name	Period 1 (1 July 1998–1 July 1999)	Period 2 (20 September 1999–17 January 2000)	Period 3 (1 September 2000–10 January 2001)
French companies	Accor	1.2%	0.9%	1.1%
	Alcatel	1.1%	0.7%	0.7%
	Aventis	1.3%	0.7%	0.9%
	Axa	1.5%	0.7%	0.6%
	Canal+	1.2%	1.9%	1.3%
	Cap Gemini	1.6%	1.1%	1.0%
	Carrefour	0.9%	0.7%	0.8%
	Danone	0.9%	0.7%	0.7%
	Elf Aquitaine	1.5%	0.8%	2.9%
	France Telecom	1.3%	1.1%	0.7%
	L'Oréal	1.3%	0.6%	0.8%
	LVMH	2.1%	0.8%	0.9%
	Peugeot	1.0%	0.7%	0.7%
	Renault	1.6%	1.3%	1.3%
	Société Générale	1.1%	0.6%	1.2%
	Saint Gobain	1.3%	1.1%	0.9%
	Suez	1.0%	0.5%	0.8%
	Total	1.4%	0.9%	0.7%
	Vivendi	0.8%	0.6%	0.6%
Average of French companies		1.27%	0.86%	0.98%
			(−4.74**)	(0.88)
German companies	Adidas	1.1%	1.2%	1.5%
	Allianz	1.6%	0.7%	1.1%
	BASF	1.4%	0.9%	2.1%
	Bayer	1.1%	0.9%	2.1%
	Daimler	0.8%	1.3%	2.1%
	Deutsche Bank	1.1%	1.2%	2.5%
	Dresdner Bank	1.5%	1.5%	1.5%
	Siemens	1.1%	0.9%	2.0%
	Volkswagen	1.3%	0.8%	1.9%
Average of German companies		1.23%	1.04%	1.85%
			(−1.35)	(5.28**)
Average of all companies		1.25%	0.9%	1.26%

** Statistically significant at 5%.

The table reports the average of the absolute value of the percentage difference between the daily opening prices in Paris and Frankfurt, for three selected periods and for all the companies in the Datastream database from July 1st, 1999 to January 10, 2001. We test if the distribution of these average values across stocks is different between two consecutive periods. The corresponding Student t-statistics are indicated in parenthesis below the two groups of stocks.

For each stock, we compute the average of the absolute value of the percentage difference between home and foreign opening prices. The results are presented in Table I.

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 are based on different information sets. The estimates are of the order of magnitude of 1 percent. 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.[11] 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 take into account 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 of the absolute value of the difference between home and foreign opening prices is greater for the first period (1.27 percent) than for the second period (0.86 percent). The difference between these two averages is significantly different from 0, with a t-statistic of -4.74. The difference between the second and the third periods is not significantly different from 0. The difference between the first period and the two following ones reflects the difference in opening times. During the first period Frankfurt opens before Paris and Frankfurt traders must value French stocks based on relatively little information. During the second and third periods the two markets open simultaneously and Frankfurt traders can use the information revealed during the preopening period in Paris.

For German stocks, the absolute value of the difference between home and foreign prices is large during the three periods. For the first period, it could reflect different opening times, not for the two other periods. Thus the results are consistent with the result from our model that, even when prices are set simultaneously, informational asymmetries can generate differences in prices. While there is no significant difference, for German stocks, between the first and second periods, the wedge between the Frankfurt and Paris markets is significantly greater in the third period. We have no clear interpretation for this fact.

While the results in Table I suggest that there is a marked difference between the Frankfurt and Paris opening prices, in accordance 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.

[11] Since the price discrepancy is measured in terms of absolute value, we do not test if it is significantly different from 0.

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 test this prediction, we need a proxy for the fundamental value of the security. We choose to use the closing (end-of-day) 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 independent from the other variables in the model.[12] To see this, denote the noise component in the proxy by 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. Thus, our test can be interpreted in terms of daily returns.

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, was able to incorporate the price discovery already achieved that morning in Frankfurt. Instead, for French stocks the differences in opening times between Frankfurt and Paris do 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 before 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 the 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 are in Table II. For the first period, we only conduct the analysis for French stocks, as explained above. For 14 stocks out of 19, the foreign variance is above the home variance, which is in line with our model. As reported in the table, the average difference between the foreign and home variances is 10^{-4}. The t-statistic for the test of equality of the average variance in the two populations is equal to 2.07. Hence, the foreign variance is significantly larger than its domestic counterpart for French stocks during the first period. This finding is consistent with our theoretical results.

For German stocks in the second and the third periods, 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 II, the average difference between

[12] Below, we consider the effect of using another proxy, to assess the robustness of our analysis.

Table II. Difference between the informational contents of the opening prices on the two markets

Nationality	Company name	Period 1 (1 July 1998–1 July 1999)	Period 2 (20 September 1999–17 January 2000)	Period 3 (1 September 2000–10 January 2001)
French companies	Accor	−0.029%	0.008%	−0.00012%
	Alcatel	0.058%	0.000%	−0.00011%
	Aventis	0.023%	−0.001%	0.00009%
	Axa	0.032%	−0.001%	0.00000%
	Canal+	−0.014%	0.105%	0.00011%
	Cap Gemini	0.034%	0.024%	−0.00007%
	Carrefour	0.013%	0.001%	−0.00003%
	Danone	0.015%	0.000%	−0.00005%
	Elf Aquitaine	0.029%	0.010%	0.00063%
	France Telecom	0.009%	−0.005%	−0.00004%
	L'Oréal	0.027%	0.005%	−0.00011%
	LVMH	−0.017%	0.001%	−0.00009%
	Peugeot	0.007%	−0.001%	0.00000%
	Renault	0.013%	0.010%	−0.00020%
	Société Générale	0.003%	−0.003%	0.00009%
	Saint Gobain	−0.024%	0.014%	−0.00006%
	Suez	0.000%	0.000%	−0.00003%
	Total	0.009%	0.007%	−0.00008%
	Vivendi	0.006%	0.002%	0.00000%
Average of French companies		−0.01%	0.009%	0.0004%
		(−2.07**)	(1.68)	(0.11)
German companies	Adidas	n.a	−0.009%	−0.042%
	Allianz	n.a	−0.019%	−0.021%
	BASF	n.a	−0.032%	−0.053%
	Bayer	n.a	−0.013%	−0.033%
	Daimler	n.a	−0.004%	−0.035%
	Deutsche Bank	n.a	−0.034%	−0.001%
	Dresdner Bank	n.a	−0.036%	−0.038%
	Siemens	n.a	−0.021%	−0.012%
	Volkswagen	n.a	−0.013%	−0.021%
Average of German companies		n.a	−0.02%	−0.028%
			(−5.20**)	(−5.30**)
Average of all companies		−0.01%	−0.0000%	−0.00001%
		(−2.07**)	(−0.03)	(−2.17**)

** Statistically significant at 5%.

In each market (Frankfurt and Paris) and for each stock, we compute the difference between the opening price and a proxy for the fundamental value. To mitigate heteroskedasticity, we divide this difference by the previous close on the domestic market. To measure the informational efficiency of each market (for each stock), we compute the variance of this percentage difference. We then subtract the variance computed for the foreign market from the variance computed for the domestic market. A positive value for this difference indicates that the domestic market is informationally more efficient. We then compute the average across each group of stocks (French or German) of this measure of the relative informational efficiency of the two markets, as well as the corresponding t-statistic, reported in parentheses.

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. This is consistent with the implications of our asymmetric information model.

Now turn to the French stocks during the second and the third periods. 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 2 and 3 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 II). 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 by $\Delta = (\Delta_j)_{j=1,\ldots N}$ 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.

The findings reported above are obtained proxying the fundamental value by the closing price on the same day. This price, however, could reflect country-specific transient inventory effects. To assess the robustness of our results relatively to this potential problem, we replicated our analysis using the closing price set one week

Table III. Robustness of the comparison between the informational efficiency of the two markets with respect to the proxy for the fundamental value

		V proxied by same day close	V proxied by following week close
French stocks	Period 1	−0.010%	−0.043%
		(−2.07**)	(−2.19**)
	Period 2	0.009%	0.106%
		(1.68)	(1.61)
	Period 3	0.000%	0.011%
		(0.11)	(1.73*)
German stocks	Period 1	n.a	n.a
	Period 2	−0.021%	−0.024%
		(−5.20**)	(−2.88**)
	Period 3	−0.028%	0.101%
		(−5.30**)	(0.85)
All stocks	Period 1	−0.010%	−0.043%
		(−2.07**)	(−2.19**)
	Period 2	−0.000%	0.064%
		(−0.03)	(1.39)
	Period 3	−0.009%	0.040%
		(−2.18**)	(1.06)

* Statistically significant at 10%.
** Statistically significant at 5%.
In Table II the fundamental value is proxied by the domestic market closing price on the same day. To assess the robustness of the results, we conducted the same analysis as in Table II, proxying the fundamental value with the closing price one week later. For simplicity we only report results averaged across stocks. To facilitate comparisons, the third column of the table reports the results shown in Table II, while the fourth column reports the results obtained when v is proxied by the closing price observed one week later. T-statistics for the significance of the difference between the informational efficiencies on the two markets are indicated in parentheses.

later, instead of the closing price for the same day. This price is not likely to be contaminated by transient inventory effects from the previous week. The results obtained with this alternative proxy for the fundamental value are presented in Table III. For French stocks, the sign of the estimates of the difference between domestic and foreign variances is the same with both proxies. In particular, for period 1, the estimate is significantly negative for both proxies. For German stocks the estimate is significantly negative for both proxies during the second period. For the third period the estimate obtained when proxying the value with the closing price one week later is not significantly different from 0. Taken together, these findings suggest our results are rather robust to the choice of proxy.

5.3. IS THE FOREIGN PRICE TOO HIGH 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 estimated this covariance for each of the stocks in our sample, and for the different periods. The averages across stocks are reported in Table IV, Panel A, along with t-statistics corresponding to the null hypothesis that the covariance is 0. The average covariances are positive in all cases and significantly different from 0. That is, when the foreign opening price is below (respectively above) its home counterpart, it is undervalued (respectively 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 (ii) the variance of the difference between the home and foreign opening prices.

The above results, suggesting that the domestic price tends to lead the foreign price, are consistent with our theoretical model. On the other hand, our model also suggests that the foreign price should not lead the domestic price. From a purely statistical point of view, however, this is not necessarily the case. The two prices could jointly contribute to the price discovery process. To investigate this point we also estimated $cov(p_f - p_d, v - p_d)$. The results are reported in Table IV, Panel B. Consistently with the view that the foreign market also impounds useful information and contributes to the price discovery process, these covariances tend to be positive. Note however that, for French stocks during the first period, and German stocks during the second period, the leadership of the domestic price is stronger than that of the foreign price. The interpretation is that news reach the domestic market first in the majority of the cases, but also sometimes reach the foreign market first. This suggests that our theoretical model, which posits that private information is available in the domestic market only, is oversimplified. A better assumption, in line with our empirical findings, would be that while the bulk of private information is available in the domestic market, smaller yet significant pieces of private information are also available in the foreign market. On the other hand, for the French stocks during the second and third periods, both our results on covariances and our results on variances are inconsistent with the hypothesis that domestic prices are informationally more efficient than foreign prices. As discussed above, this may stem from the Frankfurt specialist observing rich and relevant information from the preopening period in Paris.

Table IV. Price leadership

Panel A: Does the domestic price lead?				
Nationality	Company name	Period 1 (1 July 1998–1 July 1999)	Period 2 (20 September 1999–17 January 2000)	Period 3 (1 September 2000–10 January 2001)
French companies	Accor	−0.0028%	0.0025	0.0004
	Alcatel	0.0579%	0.0062	−0.0015
	Aventis	0.0282%	0.0055	0.0089
	Axa	0.0360%	0.0042	0.0033
	Canal+	0.0069%	−0.0145	0.0277
	Cap Gemini	0.0412%	−0.0022	0.0055
	Carrefour	0.0132%	0.0027	0.0040
	Danone	0.0140%	0.0032	0.0023
	Elf Aquitaine	0.0333%	0.0013	0.0989
	France Telecom	0.0178%	0.0113	0.0013
	L'Oréal	0.0253%	0.0006	−0.0007
	LVMH	0.0349%	0.0044	0.0022
	Peugeot	0.0129%	0.0041	0.0039
	Renault	0.0299%	0.0053	−0.0014
	Société Générale	0.0122%	0.0050	0.0164
	Saint Gobain	0.0025%	0.0025	0.0029
	Suez	0.0090%	0.0025	0.0021
	Total	0.0209%	0.0029	0.0001
	Vivendi	0.0078%	0.0025	0.0024
Average of French companies		0.02%	0.002%	0.01%
		(6.04**)	(2.3**)	(1.8*)
German companies	Adidas	n.a	0.0121%	0.0685%
	Allianz	n.a	0.0163%	0.0325%
	BASF	n.a	0.0319%	0.0693%
	Bayer	n.a	0.0191%	0.0361%
	Daimler	n.a	0.0057%	0.0283%
	Deutsche Bank	n.a	0.0293%	0.0299%
	Dresdner Bank	n.a	0.0377%	0.0577%
	Siemens	n.a	0.0183%	0.0438%
	Volkswagen	n.a	0.0115%	0.0445%
Average of German companies		n.a	0.02%	0.04%
			(5.7**)	(8.6**)
Average of all companies		0.02%	0.008%	0.02%
		(6.04**)	(4.01**)	(4.1**)

* Statistically significant at 10%.
** Statistically significant at 5%.
For each stock, we compute the difference between the opening prices on the home and foreign markets, as well as the difference between the proxy for the fundamental value and the opening price on the foreign market. To mitigate heteroskedasticity, we divide these differences by the previous domestic market close. We then compute the covariance between the two differences: $Cov(P_d - P_f, v - P_f)$. For each group of stocks (French or German), we report the average of this covariance across stocks, as well as the t-statistic corresponding to the null hypothesis that this average is equal to 0.

Table IV. Price leadership

Panel B: Does the foreign price lead?				
Nationality	Company name	Period 1 (1 July 1998–1 July 1999)	Period 2 (20 September 1999–17 January 2000)	Period 3 (1 September 2000–10 January 2001)
French companies	Accor	0.026%	0.0105%	0.0125%
	Alcatel	0.000%	0.0063%	0.0092%
	Aventis	0.005%	0.0047%	−0.0001%
	Axa	0.004%	0.0037%	0.0036%
	Canal+	0.021%	0.0907%	0.0162%
	Cap Gemini	0.007%	0.0216 %	0.0126%
	Carrefour	0.000%	0.0042%	0.0070%
	Danone	−0.001%	0.0032%	0.0074%
	Elf Aquitaine	0.004%	0.0111%	0.0358%
	France Telecom	0.009%	0.0061%	0.0057%
	L'Oréal	−0.002%	0.0061%	0.0108%
	LVMH	0.051%	0.0057%	0.0116%
	Peugeot	0.006%	0.0031%	0.0042%
	Renault	0.017%	0.0150%	0.0189%
	Société Générale	0.009%	0.0019%	0.0073%
	Saint Gobain	0.026%	0.0162%	0.0087%
	Suez	0.009%	0.0030%	0.0052%
	Total	0.012%	0.0101%	0.0079%
	Vivendi	0.002%	0.0045%	0.0027%
Average of French companies		0.01%	0.01%	0.01%
		(3.63**)	(2.64**)	(5.49**)
German companies	Adidas	n.a	0.0027%	0.0267%
	Allianz	n.a	−0.0026%	0.0112%
	BASF	n.a	0.0001%	0.0160%
	Bayer	n.a	0.0063%	0.0032%
	Daimler	n.a	0.0019%	−0.0071%
	Deutsche Bank	n.a	−0.0050%	0.0287%
	Dresdner Bank	n.a	0.0015%	0.0194%
	Siemens	n.a	−0.0031%	0.0322%
	Volkswagen	n.a	−0.0016%	0.0233%
Average of German companies		n.a	0.00%	0.01%
			(0.03)	(4.00**)
Average of all companies		0.01%	0.01%	0.01%
		(3.63**)	(2.50**)	(6.4**)

** Statistically significant at 5%.

For each stock, we compute the difference between the opening prices on the home and foreign markets, as well as the difference between the proxy for the fundamental value and the opening price on the foreign market. To mitigate heteroskedasticity, we divide these differences by the previous domestic market close. We then compute the covariance between the two differences: $Cov(P_d - P_f, v - P_f)$. For each group of stocks (French or German), we report the average of this covariance across stocks, as well as the t-statistic corresponding to the null hypothesis that this average is equal to 0.

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, in that it does not reflect non-synchronicity in the data or discrepancies due 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 (respectively Paris) have better information about the value of German (respectively 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, Roëll and Zechner (2001): "Despite the increasing integration of capital markets, geography has not yet become irrelevant to finance".

Our analysis points to the following 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.

Our theoretical model analyzes price formation for a given stock on the home and foreign markets. In further research, it would be interesting 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 improve our understanding of the home bias in connection with price discrepancies across countries.

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:

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

Equating to 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. Equating this function to the linear conjecture, $P_f = M_f + \lambda_f q_f$, one obtains the parameters of the price function on the foreign market:

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

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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