Tail Wags Dog? Time-Varying Information Shares in the Bund Market

Christian Upper
Thomas Werner

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Deutsche Bundesbank, Wilhelm-Epstein-Strasse 14, 60431 Frankfurt am Main,
Postfach 10 06 02, 60006 Frankfurt am Main

Tel +49 69 95 66-1
Telex within Germany 4 1 227, telex from abroad 4 14 431, fax +49 69 5 60 10 71

Please address all orders in writing to: Deutsche Bundesbank,
Press and Public Relations Division, at the above address or via fax No. +49 69 95 66-30 77

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Abstract

The flow of information between futures and spot prices may vary over time, in particular during periods of stress. This article analyses the information content of the Bund Future and German government bonds during 1998 and test whether it is constant over time. The use of high-frequency data permits us to capture possible imperfections in the information flows between the two markets. We measure the contributions of trading on the spot and futures markets to price discovery using the information shares approach by Hasbrouck (1995) as well as a recently proposed approach based on the Gonzalo-Granger decomposition. A state-space approach is used to estimate the underlying VECM in the presence of missing values. We test for structural breaks in the pricing relationship between the spot and futures markets and estimate break dates. Although most information is incorporated into prices in the futures market, this does not mean that the spot market is irrelevant for prices discovery. Under normal market conditions, the underlying bonds contribute to 19 to 33 % of the variation in the efficient price. The informational role of the spot market vanishes during episodes of stress. For example, during the two weeks after the recapitalization of LTCM (September 24^{th} to October 8^{th}, 1998), the information share of the spot market dropped to virtually zero and futures prices did not respond to movements in bond prices. All adjustment towards equilibrium took place in the spot market.

Key words: high-frequency data, market microstructure, future markets, information shares, kalman filter

JEL Classification: G12, G14, C32

Zusammenfassung

Der Informationsfluss zwischen Kassa- und Terminmärkten kann, insbesondere in Zeiten turbulenter Märkte, zeitlich variieren. Dieser Beitrag analysiert den Informationsgehalt im Bund Future und in den zugrundeliegenden Bundesanleihen für das Jahr 1998 und testet auf zeitliche Konstanz. Unsere Analyse basiert auf Hochfrequenzdaten und erlaubt daher die Untersuchung möglicher Unvollkommenheiten im Informationsfluss zwischen beiden Märkten. Wir messen den Beitrag der Handelstransaktionen auf dem Kassa- und Terminmarkt zum Preisbildungsprozess mit Hilfe des Informationsanteil Ansatzes von Hasbrouck (1995) sowie eines Ansatzes basierend auf der Gonzalo-Granger Zerlegung. Um das zugrundeliegende Fehler-Korrektur-Modell schätzen zu können, wenn Datenlücken vorliegen, wird ein Zustands-Raum-Modell verwendet. Wir testen auf Strukturbrüche im Preisbildungsprozess der Märkte und schätzen die Zeitpunkte der Strukturbrüche. Obwohl die meiste Information in den Preisen der Terminkontrakte enthalten sind, liefert der Kassamarkt einen nicht unerheblichen Beitrag zum Preisbildungsprozess. Unter normalen Marktbedingungen trägt die Bundesanleihe mit 19 bis 33 Prozent zur Bestimmung des Effizienzpreises bei. Der Informationsbeitrag des Kassamarktes verschwindet jedoch während Zeiten mit Marktturbulenzen. Zum Beispiel brach der Informationsanteil des Kassamarktes während der LTCM Rekapitalisierungsphase völlig zusammen. Der Terminkurs reagierte in dieser Phase nicht mehr auf Preisbewegungen am Kassamarkt und die Anpassung an das Arbitragegleichgewicht erfolgte ausschließlich durch den Kassakurs.

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"A derivative is an investment whose value ... is derived entirely from the value of another asset".
(Grinblatt & Titman (1998), p. 234)

1. Introduction

The quote at the beginning of this paper pretty accurately sums up textbook financial theory, which defines derivatives purely in terms of the underlying securities. This view is reflected not only in the word "derivatives" but also serves as the starting point for the relevant pricing models, which value derivatives solely in terms of spot securities. If such models are right, then, given the parameters of the pricing model, derivatives prices should not convey any information that is not already contained in the prices of the underlying.[1]

It is not clear, though, whether the above view is an adequate reflection of reality. Take for instance the case of the futures contract on long term German government bonds (Bund Future). The futures market is far more liquid than the spot market, as indicated by lower bid-ask spreads and far higher trading activity. Practitioners tend to quote bond prices that depend on the current price of the future. This implicitly suggests that futures prices incorporate information that is not processed in the spot market.

This paper analyses the information content of futures and spot prices in the market for German government bonds during 1998. Above all, we are interested in whether the information shares of the two market segments are constant over time, in particular during times of stress. Our period of analysis is especially suited for this purpose. A rather

* We would like to thank seminar participants at the Deutsche Bundesbank, the 1st Summer Symposium for Central Bank Researches at the Studienzentrum Gerzensee and the 9th Annual Meeting of the German Finance Association for their comments.

[1] Nevertheless, option prices may still be worth looking at as they contain information on the density of expected price changes.

tranquil first half of the year was followed by the worst turbulences in international financial markets of the past decades.[2] In addition, in August 1998 there was a fear of a shortage of deliverable bonds relative to the amount outstanding of the future, which put further strain on the market.[3]

We measure the contributions of trading on the spot and futures markets to price discovery using the information shares approach by Hasbrouck (1995) and a factor weight based on the Gonzalo-Granger decomposition first applied to financial markets by Booth, So & Tse (1999). Both methods are based on a vector error correction model (VECM) and allow to separate long-run based price movements based on information from short-run microstructure noise like bid-ask bounce. The estimation of the underlying VECM is complicated by the fact that there are by an order of magnitude more transactions in the futures market than in the underlying bonds. We deal with this problem by restating our model in state space and handle the missing observations by using a Kalman filter. The VECM from which the information shares and factor loadings are computed is estimated by maximum likelihood. Finally, we test for structural breaks in the pricing relationship between the spot and futures markets using a sequence of Chow tests suggested by Bai (1997).

Our data comprises all transactions in Bund futures and the underlying German government bonds during 1998. The use of high-frequency data is very important in this respect, since it allows us to capture possible imperfections in the information flows between the two markets. Short term disruptions in the workings of financial markets can well have long term consequences if they inflict heavy losses on market participants. From the point of view of financial stability it is therefore important to observe data in a frequency that corresponds to the decision horizon of the individual trader.

We find that most information tends to be incorporated into the efficient price in the futures market, although trades in the bond market do contain information during normal times. During the financial turbulences in the aftermath of the LTCM recapitalisation on September 23rd, however, the information share of the spot market dropped to zero and bond prices followed the futures market without contributing to price discovery.

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2 See BIS (1999) for an overview of the events in the summer and autumn of 1998. Upper (2000) analyses the implications for the market for German government bonds.

3 For a discussion of squeezes of the deliverable bonds, see Schulte & Violi (2001).

The paper extends earlier work (Upper & Werner, 2002), where we measured the lead-lag relationship between futures and bond prices during the same period. We found that during tranquil times futures prices lead spot prices by 5 to 10 minutes, although this lead broke down during the turbulences of the autumn of 1998. Nevertheless, cointegration analysis showed that this did not result in a breakdown of the arbitrage relationship linking spot and futures prices.

The paper is structured as follows. We begin with a brief section on the pricing relationship between futures and spot market as well as potential obstacles to arbitrage. This is followed by an outline of the microstructure of the bond and futures markets in Germany and a presentation of the data. Section 4 discusses two approaches for computing information shares and factor weights, respectively. In section 5 the model is recast in state space form, so it can be estimated using the Kalman filter in order to account for missing data. The following section discusses how to test for unknown breakpoints. Our results are presented in section 7 and a final section concludes.

2. Spot-futures pricing relation and obstacles to arbitrage

Under the assumption that no arbitrage opportunities exist, the price f of a futures contract corresponds to the price s of the underlying on the spot market plus a cost of carry c:

$$f = s + c. \quad (1)$$

In the case of bond futures, the cost of carry can be decomposed into the interest earned on the bond and the cost of financing the bond position, typically through a repo transaction.

The deviation between the theoretical futures price described in equation (1) and its actual price f* on the market is called the basis. In algebraic terms, $b = f^* - f = f^* - s - c$. In practice the basis is normally close to, but not identical to, zero. This suggests that arbitrage is less than perfect. There are several reasons for why this may be the case. Bid-ask spreads in the futures, spot and repo markets may prevent arbitrageurs from ironing out small deviations of the basis from zero. In this case, we would expect prices to fluctuate freely until the basis reaches a threshold given by the trading costs in the relevant market segments and arbitrage kicks in. Another reason for a basis different from zero is the fact that in the real world arbitrage does involve risks. Potential arbitrageurs face at least three distinct types of risk. Firstly, prices may move between the execution of the different legs of a trade. This may be an issue if it is not possible to transact in the spot, futures and repo market simultaneously. Secondly, holding a position may impose considerable capital requirements or margin calls even if it is in principle fully hedged. Thirdly, the holder of a short position in bonds and a long position in the future may end up with the 'wrong' bond if the cheapest-to-deliver changes. All these factors imply that we should not expect equation (1) to hold strictly at any point in time. Instead, it can be seen as an attractor, to which prices should return after temporary deviations.

3. Market microstructure and data

The futures contract on German Government bonds (Bund Future) traded on Eurex has become the prime vehicle for hedging long term interest rate risk in the euro area. The contract refers to a notional German government bond with a face value of 250,000 DM[4] and a coupon of 6 %. At expiry of the contract, the sellers of the future can choose to deliver any German government bond (Bundesanleihe) with a residual maturity of 8½ to 10½ years at a predetermined price. The bonds are converted into the notional bond by multiplying the face value with a conversion factor that accounts for differing coupons and maturities. Since this adjustment is not perfect, it may be cheaper to fulfil ones obligations from a futures position by delivering one rather than another issue. Consequently, only one of the bonds contained in the basket, the so-called cheapest-to-deliver, tends to be delivered.[5]

In 1998, the microstructure of the futures market for German government bonds was very different from that of the spot market, although the differences have narrowed somewhat since then. While Bund future was traded electronically on the derivatives exchange Eurex[6], bond trading was much more dispersed. Although the bulk of the transactions took place over-the-counter, either by telephone or through inter-dealer brokers, bonds were also traded on the Frankfurt Stock Exchange as well as on regional exchanges. However,

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4 The Euro Bund future, which replaced the Bund future in the transition to EMU, has a contract value of 100,000 Euro.

5 For the precise formula as well as the intuition behind it, see Steiner & Bruns (2000) or any other derivatives textbook. An extensive discussion of the institutional arrangements behind the Bund future is provided in Schulte & Violi (2001).

6 A virtually identical contract was traded on LIFFE, but had lost most of its market share by 1998.

transactions on the exchanges tended to be small and their share in total turnover was therefore low.[7]

The data on Bund futures is from Deutsche Börse AG and includes all transactions on Eurex in the contracts with the expiry dates March, June, September and December 1998 between January 2nd and December 7th, 1998. Data on the German bond market has been obtained from the German securities regulator (Bundesamt für den Wertpapierhandel – BAWe), which receives notice of all transactions where at least one of the counterparts is located in Germany.[8] It has the advantage of including OTC transactions in addition to those executed on organised exchanges, but unfortunately does not contain any offshore trading. According to market participants, a considerable proportion of the trading that used to take place outside Germany has migrated back during the 1990s, so the exclusion of offshore trading does not seem to be too serious.

In contrast to much of the literature, our analysis is based on transaction prices rather than quotes. In part, this is driven by the availability of data as quotes are simply not available in the bond market. But even if they were, we believe that the use of transactions would be justified. In contrast to organized exchanges like Eurex, quotes in OTC-market are not legally binding. While of little importance in normal times, this feature can become crucial in times of stress. According to market sources, many market makers prefer to quote unreasonable quotes if they do not want to trade rather than not quoting at all. Under such circumstances, the use of quotes can be misleading. Transactions prices, in contrast, reflect the actual market price at the time of the trade. They do, however, contain a certain amount of noise due to the bid/ask-bounce. Nevertheless, this should not affect the permanent component, or efficient price, which are the basis of our measures of the information shares.

Given the staggered nature of the Bund future, we create a long time series by considering only the contract that on a given trading day was most actively traded. Since trading is concentrated on the nearby maturity and switches to a new contract within days just before

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7 More recently, the spot market for German government bonds has been transformed, first by the advent of the electronic trading systems EuroMTS in early 1999. However, it was not until the inclusion of bonds into the Eurex trading platform in late 2000 that it became possible to trade futures and bonds simultaneously on a unified trading platform, thus eliminating the risks arising from non-synchroneous trading. Since these changes took place after the end of our sample period, they need not concern us here.

8 A detailed description of the data can be found in Upper (2000).

expiry, our long series contains more than 95 % of all transactions. We construct a similar series for the spot market. The difficulty here is to predict which bond is cheapest-to-deliver at the maturity of the future. Fortunately, as long as market interest rates remain below 6%, the construction of the Bund Future implies that this will be the bond with the lowest duration in the basket. With 10 year rates around 4% throughout the sample, the probability of a switch in the cheapest-to-deliver was virtually nill. We thus construct a long series that contains all transactions of the lowest-duration bond contained in the basket of deliverables. In order to ensure comparability with the futures, we convert bond prices into future-equivalents. For this purpose we require repo rates with maturities coinciding with the expiry dates of the future contracts, which could not be obtained. Instead, we use the 2-months FIBOR.

Table 1

Summary statistics

(January, 2nd to December 7th, 1998)

Series	Bund future	Cheapest-to-deliver bond
No. Trades	2,111,602	19,186
Total volume (DM billion)	20,786	375
Average trade size (DM million)	9.8	19.6
Effective bid-ask spread[1] (bps of face value)	1.2	10.5

[1] Roll (1984) statistic.

Summary statistics of the two series are reproduced in table 1. Trading activity in the futures market by far exceeds that in the underlying bonds. In 1998, there were around 200 times as many transactions in the future than in the spot market. This discrepancy is huge by any standard, even if we account for the fact that our bond data does not contain offshore transactions. Trading costs are much lower in the futures than in the spot market. The effective bid-ask spread, which measures the cost of an instantaneous return trade, for the Bund Future is only one tenth of that in the bond market. Perhaps related to the future's role as a hedging instrument, the average trade size is only about half of that in bonds.

There are several reasons for why activity in the futures market exceeds that in the spot market:

1. Cash requirements for trading in the futures market are much lower than those in the spot market as traders have to post a margin when entering a position rather than

purchase a bond outright. Settlement of the future takes place at maturity, but traders tend to close positions by offsetting trades in order to avoid the physical delivery of the underlying.

2. Traders can easily take short positions by selling the future. Shortening a bond is more difficult since traders first have to enter a repo transaction to borrow the bond they wish to sell.
3. Liquidity in the futures market is concentrated on the nearby maturity, which is traded on a single electronic trading platform. Trading in the bond market is more fragmented in two respects. Firstly, in contrast to futures of different maturities existing bonds continue to be traded after a new one has been issued. Nevertheless, the most recent issue tends to be more liquid than the off-the-run bonds, presumably because the latter have been picked up by long term investors who transact less frequently. However, this is not necessarily the issue which is most convenient for delivery in the futures market. Secondly, liquidity may be much more dispersed than in the futures market as trading takes place over the phone or, after 1999, on one of several electronic platforms.

4. The measurement of price discovery

Two competing methodologies to measure the relative contributions of two markets to price discovery have appeared in the literature. Both are based on a decomposition of transaction prices into a permanent component associated with the fundamental or efficient price of the asset, and a transitory component which reflects noise such as the bid-ask bounce. In our case, where the two markets are linked by an arbitrage condition, the fundamental or efficient price should be identical in both markets, while the transitory component may differ. The question is in which market information is first incorporated into the efficient price.

The two methodologies differ in how the permanent component is identified. Hasbrouck (1995) uses a Stock & Watson (1988) common stochastic trend decomposition to decompose transaction prices into a random walk, which he interprets as the efficient price, and noise. He then measures the contribution of each market to the variance of the former. Unfortunately, the information shares (IS) are not uniquely defined if the price innovations in the two markets are correlated. In this case, one has to compute upper (lower) bounds for the information shares by attributing as much (little) news as possible to each market.

The approach by Gonzalo & Granger (1995), which was introduced into finance by Booth, So & Tse (1999), does not suffer from this problem as the contributions of each market are uniquely defined. They decompose transaction prices into a permanent component, which is integrated of order 1, and a transitory component that is stationary. In order to obtain a unique decomposition, they assume (i) that the permanent component is a linear combination of the prices in both markets, and (ii) that the transitory component does not Granger-cause the permanent component in the long run. The drawback of the GG approach is that the permanent component need not be a random walk and may therefore be forecastable. As pointed out by Hasbrouck (2002), this violates the condition that the efficient price should be a Martingale.

We can compare the two measures in a general framework.[9] Let $\mathbf{p}_t$ be a vector of prices of securities related by arbitrage. Each individual price series is non-stationary but, because of arbitrage, the series will be cointegrated. The multivariate price process can be put in a vector error correction model[10] (VECM)

$$\Delta\mathbf{p}_t = \Pi\mathbf{p}_{t-1} + \sum_{j=1}^{k-1}\mathbf{A}_j\Delta\mathbf{p}_{t-j} + \mathbf{u}_t\,. \qquad (1)$$

In our case, the system is bivariate and the vector $\mathbf{p}_t = (p^{future}, p^{spot})'$ is a composition of the futures and spot prices. The basis $p^{future} - p^{spot}$ should be zero on average because of arbitrage, which yields the cointegrating vector (1,-1)'. As a consequence the matrix Π has rank one and can be written as

$$\Pi = \begin{pmatrix} \alpha_1 & -\alpha_1 \\ \alpha_2 & -\alpha_2 \end{pmatrix}.$$

This implies error correction terms $\alpha_1(p^{future} - p^{spot})$ and $\alpha_2(p^{future} - p^{spot})$ where α_1 and α_2 are the adjustment coefficients or loading factors.

The IS measure by Hasbrouck is based on the Stock Watson decomposition. Two steps are necessary to reach this decomposition. In the first step the VECM equation (1) can be transformed into a moving average representation[11]

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9 See for example Baillie et al. (2002).

10 This is justified by the Engle-Granger representation theorem, see for example Watson (1994).

11 Here $\mathbf{C}(L) = I + \mathbf{C}_1 L^1 + \mathbf{C}_2 L^2 + \ldots$, is a matrix polynomial in the lag operator L with $L^p\,\mathbf{x}_t = \mathbf{x}_{t-p}$, $\mathbf{C}=\mathbf{C}(1)= \mathbf{C}_1 + \mathbf{C}_2 + \ldots$

$$\Delta \mathbf{p}_t = \mathbf{u}_t + \mathbf{C}_1\mathbf{u}_{t-1} + \mathbf{C}_2\mathbf{u}_{t-2} + \ldots = \mathbf{C}(L)\mathbf{u}_t.$$

Adding and subtracting $\mathbf{C}(1)\mathbf{u}_t$ from the right hand side of this equation yields

$$\Delta \mathbf{p}_t = \mathbf{C}(1)\,\mathbf{u}_t + [\mathbf{C}(L) - \mathbf{C}(1)]\,\mathbf{u}_t.$$

In the second step, we solve backward for the level of $\mathbf{p}_t$,[12]

$$\mathbf{p}_t = \mathbf{C}(1)\sum_{s=1}^{t}\mathbf{u}_s + \mathbf{C}(L)^*\,\mathbf{u}_t + \mathbf{p}_0.$$

The vector $\mathbf{p}_t$ is decomposed into a permanent component $\mathbf{C}(1)\sum_{s=1}^{t}\mathbf{u}_s$ and a transitory component $\mathbf{C}(L)^*\,\mathbf{u}_t$. If, in the bivariate case, the two variables are cointegrated, the matrix $\mathbf{C}(1)$ has rank 1 and the two rows of this matrix are the same and both are (c_1, c_2). This implies that there is one common stochastic trend. Since this is a random walk and hence a martingale, Hasbrouck identifies it with the efficient price. Let $\mathbf{\Omega} = \begin{pmatrix} \omega_1 & \omega_{12} \\ \omega_{12} & \omega_2 \end{pmatrix}$ be the covariance matrix of the innovation vector $\mathbf{u}_t=(u_1, u_2)=(u^{future}, u^{spot})'$. The contribution of the price innovations to the efficient price is $w = (c_1, c_2)\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \mathbf{cu}$, with variance Var(w) = $E(\mathbf{cuu'c'}) = \mathbf{c\Omega c'}$. If Ω is diagonal, implying $\omega_{12}=0$, then Var(w) = $c_1^2\omega_1 + c_2^2\omega_2$. Hasbrouck defines the information shares as the relative contributions of the *variances* of the price innovations:

$$S_1 = \frac{c_1^2\omega_1}{\mathbf{c}\Omega\mathbf{c}'}$$

and

$$S_2 = \frac{c_2^2\omega_2}{\mathbf{c}\Omega\mathbf{c}'}.$$

If the covariance matrix Ω is not diagonal, we have to orthogonalize the innovation vector $\mathbf{u}_t$. Hasbrouck (1995) proposed to triangularize the covariance matrix. He uses a Cholesky factorisation to obtain the lower triangular matrix $\mathbf{F}$ such that $\mathbf{FF'} = \Omega$. The vector $\mathbf{u}$ can now be decomposed as $\mathbf{u} = \mathbf{Fz}$. were $\mathbf{z}$ is a random vector with covariance matrix $\mathbf{I}$.[13] Now

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[12] In this term $\mathbf{C}^*(L) = (1-L)^{-1}[\mathbf{C}(L)-\mathbf{C}(1)]$ is a lag polynomial.

[13] $\mathbf{I}$ is the two dimensional identity matrix. The covariance matrix of $\mathbf{u}$ is then $E(\mathbf{uu'})=E(\mathbf{Fzz'F'})=\mathbf{F}E(\mathbf{zz'})\mathbf{F'}=\mathbf{FF'}=\Omega$, as supposed.

the variance of w can be computed as Var(w) = E(**cFzz'F'c'**) = **cF**E(**zz'**)**F'c'**. It follows with $\mathbf{cF} = (c_1, c_2)\begin{bmatrix} F_{11} & 0 \\ F_{21} & F_{22} \end{bmatrix} = (c_1 F_{11} + c_2 F_{21}, c_2 F_{22})$ that variance of the efficient price can be decomposed as Var(w) = $(c_1F_{11}+c_2F_{21})^2 + (c_2F_{22})^2$. The information shares are.

$$S_1 = \frac{(c_1 F_{11} + c_2 F_{21})^2}{\mathbf{c}\Omega\mathbf{c}'}$$

and

$$S_2 = \frac{(c_2 F_{22})^2}{\mathbf{c}\Omega\mathbf{c}'}.$$

The Cholesky factorisation depends on the ordering of the variables. Therefore the information shares are not unique unless Ω is diagonal. It is common in the literature to use the results of different orderings as upper and lower bounds. The only open question is how to compute the vector (c_1, c_2). Martens (1998) has shown that this vector is, up to scalar factor, orthogonal to the vector of loading factors $(\alpha_1, \alpha_2)'$ from the VECM. As we will see later, c_1 and c_2 are identical to the factor weights of the GG approach. Because the scalar factor cancels out, the information shares are direct functions of the loading factors. This is very important for two reasons. Firstly, there are studies using directly the loading factors to discuss the question of price discovery without referring on formal information measures[14]. The result by Martens links the Hasbrouck measure with this literature. Secondly, the information measure based on the Gonzalo-Granger decomposition is also related to the loading factors.

The basic idea behind the GG decomposition is to decompose the non-stationary vector $\mathbf{p}_t$ in a non-stationary (permanent) component $\mathbf{f}_t$ and a stationary (transitory) component $\tilde{\mathbf{p}}_t$, or formally

$$\mathbf{p_t} = \mathbf{A_1 f_t} + \tilde{\mathbf{p}}_\mathbf{t}.$$

In contrast to the approach by Hasbrouck (1995), the permanent component $\mathbf{f}_t$ is not necessarily a random walk. Since there are infinite many possibilities to decompose a non-stationary time series in a non-stationary and a stationary component, Gonzalo and Granger impose two identification restrictions:

14 See for example Harris et al (1995).

1. $\mathbf{f}_t$ is a linear combination of the series $\mathbf{p}_t$.
2. The transitory component $\tilde{\mathbf{p}}_t$ does not Granger-cause the permanent component $\mathbf{f}_t$ in the long run.

Under these assumptions the permanent component $\mathbf{f}_t$ is given by

$$\mathbf{f}_t = \gamma\, \mathbf{p}_t,$$

where $\gamma = (\gamma_1, \gamma_2)$ is a vector orthogonal to the loading factors. Using the normalisation rule $\gamma_1 + \gamma_2 = 1$, the factors γ_i can be interpreted as the contributions of the prices to the permanent component. Gonzalo and Granger (1995) have shown that the vector γ is orthogonal to the vector of loading factors. The "factor weights" are[15]:

$$\gamma_1 = \frac{\alpha_2}{\alpha_2 - \alpha_1}$$

$$\gamma_2 = \frac{\alpha_1}{\alpha_1 - \alpha_2}.$$

If we interpret the transitory component as microstructure noise, like the bid-ask bounce, it is very plausible to assume that this noise component should not Granger-cause the efficient price in the long run. But it is important to notice that the permanent component is not necessarily a random walk. Hasbrouck (2002) criticises the GG approach for that reason.

There is an ongoing debate[16] about the appropriateness of the two measures of price discovery. One important point in this debate, we think, is the question whether the unobservable efficient price is a martingale. Hasbrouck argues that this must be the case for a sensible interpretation. This argument is based on the efficient markets hypothesis, but it is only true if there are enough risk-neutral arbitrageurs in the market which drive prices to their fundamental values. In contrast, the permanent component on which the GG measure is based is not necessarily a martingale and therefore might be forecastable. This permanent component, unlike the random walk component of the IS measure, can be

[15] You have only to solve the equations $\gamma_1\alpha_1 + \gamma_2\alpha_2 = 0$ (orthogonality) and $\gamma_1 + \gamma_2 = 1$.

[16] See the survey article by Lehmann (2002) and the other articles in the same issue of the Journal of Financial Markets.

constructed as a linear combination of the contemporary prices. It is therefore possible to interpret the weights of the GG measure as a kind of portfolio weights.

Another point in the debate is the treatment of the variances of the price innovations in the markets. The debate has shown that both measures depends on the error correction mechanism, and are therefore close relatives, but the GG approach includes only information of the error correction phenomenon. Hasbroucks's approach instead uses also the variances of the price innovations and has more general economic appeal because the innovations include information about news and this should be recognised.[17]

Nevertheless, the GG measure contributes useful information about the equilibrium adjustment that we will use later.

5. Estimation of the VECM with missing values

The transactions of the bonds and the futures occur at irregular intervals, and their frequency differs between the two markets. The usual approach to handle unequally spaced data is to split the time axis into subperiods of a fixed length and consider the last transaction in every interval only. If an interval is empty, then the last available value is used. This "fill-in" approach has an important drawback: non-trading may produce a lower information share for the less frequent trading market even if the trades that take place do contain information. To circumvent this problem we use a state space method to handle the missing value problem.

The idea underlying a state space model is that the development of the system over time is determined by the (unobservable) state vector α_t and the state equation[18]. Because the state vector cannot observed directly the analysis of the system must be based on the vector of observable variables $\mathbf{y}_{t.}$ This vector can contain missing values. The observation equation links the observations with the state vector. The system can be written as

$$\mathbf{y}_t = \mathbf{Z}\boldsymbol{\alpha}_t + \boldsymbol{\varepsilon}_t \qquad \text{(observation equation)}$$

$$\boldsymbol{\alpha}_t = \mathbf{T}\boldsymbol{\alpha}_{t-1} + \boldsymbol{\eta}_t \qquad \text{(state equation).}$$

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[17] This argument is stressed by Baillie at al. (2002).

[18] For a recent and comprehensive survey of state space models see Durbin and Koopmann (2001).

The error terms ε_t and η_t are both multivariate normally distributed with zero mean and covariance matrix **Q** and **H** respectively. The VECM of equation (1) can be written in a state space form using **Q** = **0**, $\mathbf{A}_1^* = \mathbf{I} + \begin{pmatrix} \alpha_1 & -\alpha_1 \\ \alpha_2 & -\alpha_2 \end{pmatrix} + \mathbf{A_1}$, $\mathbf{A}_p^* = -\mathbf{A_{p-1}}$, and $\mathbf{A}_j^* = \mathbf{A}_j - \mathbf{A}_{j-1}$ for j = 2,...p-1.The resulting state space model has the form[19]:

-*state equation*

$$\begin{pmatrix} \mathbf{p}_t \\ \mathbf{p}_{t-1} \\ \vdots \\ \mathbf{p}_{t-p+1} \end{pmatrix} = \begin{bmatrix} \mathbf{A}_1^* & \mathbf{A}_2^* & \cdots & \mathbf{A}_p^* \\ \mathbf{I} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \vdots & \vdots & \vdots & \vdots \\ \mathbf{0} & \cdots & \mathbf{I} & \mathbf{0} \end{bmatrix} \begin{pmatrix} \mathbf{p}_{t-1} \\ \mathbf{p}_{t-2} \\ \vdots \\ \mathbf{p}_{t-p} \end{pmatrix} + \begin{pmatrix} \mathbf{u}_t \\ \mathbf{0} \\ \mathbf{0} \\ \mathbf{0} \end{pmatrix}$$

-*observation equation*

$$\mathbf{y}_t = \begin{bmatrix} \mathbf{I} & \mathbf{0} & \cdots & \mathbf{0} \end{bmatrix} \begin{pmatrix} \mathbf{p}_t \\ \mathbf{p}_{t-1} \\ \vdots \\ \mathbf{p}_{t-p+1} \end{pmatrix}.$$

To estimate the parameters of a state space model by maximum likelihood it is necessary to compute the likelihood function. The state vector is not observable in general, in our case it is only partially observable because of the missing values, so we cannot compute the likelihood directly. A usual way to compute the likelihood of a state space model is to use the Kalman filter. A brief description of the algorithm and the computational implementation can be found in the appendix. Here we limit our discussion to the intuition that lies behind our estimation method. Given the parameter values of the VECM, the Kalman filter is used to compute the likelihood of the model. This is done by a recursive computation of the bond and futures prices based on the VECM. Actual prices are used if available, otherwise we use the values predicted by the model during the last recursion step. We then calculate the likelihood on the basis of the differences between the actual values and the values predicted by the model. For the first iteration, we use an auxiliary data set containing the price of the last available transaction and OLS estimates of the parameter values as starting points. We then use a non-linear optimisation method to adjust the parameter values as long as improvements in the likelihood is possible. It is important

[19] In this expressions **I** is the identity matrix and **0** is the null matrix.

to note that the VECM and the missing values are estimated simultaneously. As a consequence, the existence of missing values in one market does not imply a lower information share in this market.

6. Testing for structural changes

We have shown that the two measures of the information content presented in section 4 are functions of the loading factors. Therefore we should test the constancy of these factors to asses the stability of the price discovery process.

Ideally, we would like to model the loading factors of the VECM as time varying parameters, e.g. by using a state-space approach that treats them as an unobservable state variables. In our case, we already use a state space approach to deal with the issue of missing values. Adding unobservable parameters in this approach turned out to be infeasible. Since we believe that the missing-value problem is important, we decided to test for unknown structural changes. The classification of different time periods gives nearly the same information as time varying parameters.

The classical test for structural change is attributed to Chow (1960). His procedure is based on a sample split in two subperiods and a F statistic to test for the equality of the two sets of parameters. It is important to note that the Chow test is based on a known breakdate. Quandt (1960) extended the Chow test to treat unknown breakdate and supposed the largest pointwise Chow test as a test statistic. Unfortunately the distribution of this statistic remained unknown for three decades[20]. The problem was solved by Andrews (1993), who developed a distribution theory for structural change testing with unknown breakdates in a very general GMM framework. He considered a parametric model with parameter vector β and the null hypothesis:

$$H_0: \beta_t = \beta_0 \text{ for all } t \geq 1,$$

and an alternative with change point $\pi \in (0,1)$ [21]:

$$H_1(\pi) : \beta_t = \begin{cases} \boldsymbol{\beta}_1(\pi) & \text{for } t = 1,\cdots,T\pi \\ \boldsymbol{\beta}_2(\pi) & \text{for } t = T\pi + 1,\cdots,T. \end{cases}$$

[20] For a survey on new development in structural change testing see Hansen (2001).

If π is known, one can form a Wald, LM, or LR-like test for testing H_0 against $H_1(\pi)$. In the case of unknown π, Andrews shows the asymptotic properties and reports asymptotic critical values of the statistics:

$$\sup_{\pi \in \Pi} F(\pi),$$

where $F(\pi)$ is the corresponding Wald, LM, or LR statistic and Π is some pre-specified subset of (0,1). In this test the π that maximises $F(\pi)$ will be the estimated date of the break point.[22] In principle all three types of tests (Wald, LM, or LR) are equivalent. In our case only the Lagrange Multiplier test is feasible in terms of computing time as it is based on the parameters estimated under the null Hypothesis.

7. Empirical Results

We estimate the VECM with three lags[23] and test for parameter stability using a method proposed by Bai (1997), which is based on a sequence of break point tests. It begins with the complete sample and subsequently tests for the most likely breakpoint until the resulting subsamples are stable. The results are collected in table 2. There is a break on day 105, nearly in the middle of the data set. The next break is on the day 136. There is no break in the first interval (day 105 to day 136), so we can continue with the second part (day 137 to 236). We perform this procedure until we find not further breaks. Two phases are of special interest. Both the Aug. 21st – Sept. 23rd and the Sept. 24th – Oct. 8th intervalls are relatively similar (but not identical) to the Russia and LTCM phases identified by the BIS (1999).[24] This is noteworthy as we estimated these phases without any information beyond spot and futures prices. We check the robustness of the break points by putting together two adjacent stable intervals and reestimating the break date.

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21 If T is the sample size than πT is the time of change.

22 Se for example McConnell & Perez-Quiros (2000).

23 Because of computational problems we didn't use formal information criteria. With three lags the estimations converges nicely. In the case of four lags the convergence of the estimation is much slower and the parameters of the last lag are mostly insignificant. Therefore a lag length of three seems to be appropriate.

24 See chronology in the appendix.

Table 2

Test Statistics and Break Points

Sample	Dates	Sup-LM[25]	Break Date
[1-236]	Jan. 2nd - Dec. 7th	120.24*	105
[106-236]	June 5th - Dec 7th	59.12*	136
[106-136]	June 5th - July 20th	6.15	-
[137-236]	July 21st - Dec 7th	17.12*	183
[137-183]	July 21st -Sep. 23rd	43.95*	159
[137-159]	July 21st -Aug. 20th	32.05*	145
[146-159]	Aug. 3rd - Aug. 20th	5.28	-
[137-145]	July 21st - July 31st	2.21	-
[160-183]	Aug. 21st -Sep 23rd	8.27	-
[184-236]	Sep 24th- Dec. 7th	33.18*	194
[184-194]	Sep. 24th- Oct. 8th	11.89	-
[195-236]	Oct. 9th -Dec 7th	16.14*	219
[195-219]	Oct 9th -Nov. 12th	8.12	-
		Robustness	
[146-183]	Aug. 3rd -Sep 23rd	50.51*	159
[160-194]	Aug. 21st - Oct. 8th	49.12*	184
[184-219]	Sep 24th -Nov. 12th	23.04*	194

Our estimates for the GG and IS measures for the various subperiods is assembled in Table 3. During the first half of the year, the lower and upper limit of the IS measure are 19% and 33% for the bond, while the GG measure is 17%. This indicates that the information content of the future is greater than that of the bond, although the latter still contributes to the price discovery in a non-negligible way.

[25] A star signals significance at the 1% level. The critical value depends on the number of parameters and the fraction π_0 of the symmetric interval $[\pi_0, 1-\pi_0]$ used for the estimation. We use $\pi_0 = 0.2$ and the critical value is 15.09, see Andrews (1993) p. 840.

Table 3

Estimation of the Information Content for the Bond

Period	Dates	GG	IS (lower limit)	IS (upper limit)
First Half of 1998	Jan. 2nd – June 3rd	17%	19%	33%
	June 5th-July 20th	8%	7%	14%
	(July 21st- July 31st)*	*(34%)*	*(45%)*	*(57%)*
	Aug. 3rd – Aug. 20th	2%	0%	6%
Russia	Aug. 21st – Sept. 23rd	20%	14%	37%
LTCM	Sept. 24th – Oct. 8th	-8%	0%	2%
	Oct 9th- Nov. 12th	11%	9%	25%
	Nov. 13rd-Dec. 7th	25%	20%	38%

* Estimates are not reliable because we could not achieve strong convergence for the maximum-likelihood estimation due to short sample.

The results for the second half of the year differ considerably between the individual phases. The information content of the bond market during June, much of July, and the first half of August is considerably lower than that observed during the first half of the year.[26]

It is interesting to see what happens during the turbulences in the international financial markets in the wake of Russia's devaluation and default on August 17, 1998. Until late September, the information content of bond trading remains roughly comparable to the tranquil first half of the year period. One reason for this could be due to safe-haven effects, where funds are "parked" in German government bonds.[27]

The picture changes completely in the aftermath of the LTCM recapitalisation on September 23rd, when the information share of the bond breaks down and becomes virtually zero when measured by Hasbrouck's method. The GG based measure even

[26] We omit the subperiod ranging from July 21st to July 31st, which shows an information share of the spot market of about one half, as this seems to be due to econometric problems associated with the low number of observations.

[27] See Deutsche Bundesbank (2000).

indicates a *negative* contribution to price discovery. The technical reason for this is that the adjustment coefficient of the future has the “wrong” sign. During “normal” times the adjustment coefficients of spot and future prices have opposite signs and consequently adjust towards the equilibrium. During the LTCM phase only the price of the bond adjusts towards the equilibrium, while the futures price moves away. This does not mean that equilibrium is not restored eventually, but suggests that the futures market leads both markets and all adjustment towards arbitrage equilibrium takes place in the bond market. Earlier work by Upper & Werner (2002) has shown that the prices of the future and the cheapest-to-deliver bond were cointegrated even during this period of extreme stress. Therefore the negative GG measure should not be interpreted as a distortion of the futures market prices from the bond market prices.

The LTCM-episode lasts until October 8th. Afterwards, the information content of the spot market gradually increases and after mid-November reaches values similar to those during the reference period.

8. Conclusions

In this paper, we compare the information content of trading in the futures market with trading in the spot market during 1998. We found that under normal market conditions the information share of the Bund Future is considerable higher than that of the underlying bonds. This confirms earlier work that shows that future prices lead stock prices by 5 to 10 minutes. This does not mean, however, that the spot market does not process any information at all, as it still contributes to 19 to 33 % of the variation in the efficient price.

The role of the spot market in processing information may break down in times of stress. During the two weeks after the recapitalization of LTCM (September 24th to October 8th, 1998), its information share declines to zero. During this period, the price of the future does not adjust at all to movements in the price of the underlying bond. It is important to stress that this does not mean that the arbitrage relationship between the two is impaired. Instead, all the adjustment towards equilibrium takes place exclusively in the spot market. This is consistent with anecdotal evidence that during times of stress bond traders merely follow the events in the futures market.

The results have important implications for the users of financial indicators. They suggest that futures prices should be more robust indicators than bond prices. While this may not matter much from the point of view of a macroeconomist who works with low frequency data, it may well be relevant for identifying a breakdown in market functioning. As was mentioned in the introduction, short term price movements may well have long term consequences if they impose heavy losses on market participants.

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Appendix

Kalman filter

Let $\mathbf{a}_t$ denote the optimal estimator of the state vector α_t based on all information up to time t. The covariance matrix of the associated estimation error is

$$\mathbf{P}_t = E[(\boldsymbol{\alpha}_t - \mathbf{a}_t)(\boldsymbol{\alpha}_t - \mathbf{a}_t)'] \ .$$

Suppose that $\mathbf{a}_{t-1}$ and $\mathbf{P}_{t-1}$ are given at time t-1. The Kalman filter is based on two steps each iteration.

-*prediction step*

An optimal estimator of α_t is given by

$$\mathbf{a}_{t|t-1} = \mathbf{T}\mathbf{a}_{t-1}$$

and

$$\mathbf{P}_{t|t-1} = \mathbf{T}\mathbf{P}_{t-1}\mathbf{T}_t^{'} + \mathbf{H}$$

where the index t|t-1 means prediction of the time t value using information up to time t-1 only. The corresponding estimator of $\mathbf{y}_{t.}$ is

$$\tilde{\mathbf{y}}_{t|t-1} = \mathbf{Z}\mathbf{a}_{t|t-1}$$

and the covariance matrix of the prediction error $\mathbf{v}_t = \mathbf{y}_t - \tilde{\mathbf{y}}_{t|t-1}$ is $\mathbf{F}_t = \mathbf{Z}\mathbf{P}_{t|t-1}\mathbf{Z}'$. The prediction error together with the covariance matrix can be used to calculate the likelihood.

-*updating step*

In this step the observation $\mathbf{y}_t$ is used to update the estimator of the state vector ($\alpha_t = \mathbf{a}_t$) and the covariance matrix

$$\mathbf{a}_t = \mathbf{a}_{t|t-1} + \mathbf{P}_{t|t-1}\mathbf{Z}'\mathbf{F}_t^{-1}(\mathbf{y}_t - \mathbf{Z}\mathbf{a}_{t|t-1})$$

and

$$\mathbf{P}_t = \mathbf{P}_{t|t-1} - \mathbf{P}_{t|t-1}\mathbf{Z}'\mathbf{F}_t^{-1}\mathbf{P}_{t|t-1}.$$

If $\mathbf{y}_{t.}$ is not available (because of missing values) the update becomes

$$\mathbf{a}_t = \mathbf{a}_{t|t-1}$$
$$\mathbf{P}_t = \mathbf{P}_{t|t-1}.$$

If the vector $\mathbf{y}_{t.}$ is observed partially all the calculations can be performed with reduced number of rows of the **Z** matrix.

Computing this steps recursively for the whole data set with n time points allows to calculate the log-likelihood function by

$$-\frac{nN}{2}\log(2\pi) - \frac{1}{2}\sum_{i=1}^{n}\left(\log|\mathbf{F}_t| + \mathbf{v}_t'\mathbf{F}_t^{-1}\mathbf{v}_t\right),$$

where N is the number of variables in the $\mathbf{y}_{t.}$ vector.

To estimate the parameters of the underling VECM it is necessary to maximise the log-likelihood function numerically. In every step of the numerical optimisation method the Kalman filter has to be computed if an evaluation of the log-likelihood function is needed. This task is computationally very expensive and a fast implementation is necessary. The computations of this paper are performed in Ox using the Ox state space package SstPack 2.2 of Koopman, Shephard and Doornik (1999). Despite this fast programming environment the estimation process is slow and up to two hours are necessary to estimate the parameters for one specification.

Table A1

Chronology

Dates	**Events**
I. July 6th – Aug.14th	Mounting tensions
	July 6th: Salomon Brothers arbitrage desk disbanded
	July 14th. IMF approves Russia loan package
	July 20th: First Wall Street Journal on LTCM losses
II. Aug.17th – Sept. 22nd	Russia
	Aug.17th: Russian effective default and rouble devaluation
	Sept.1st. Malaysia imposes capital controls
	Sept.2nd: LTCM shareholder letter issued
	Sept.4th. First WSJ headline on Lehman Brothers' losses
III. Sept.23rd – Oct. 15th	LTCM
	Sept.23rd: LTCM recapitalisation
	Sept.29th: Federal Reserve interest rate cut
	Early Oct.: Interest rate cuts in Spain, UK, Portugal and Ireland
	Oct. 7/8th: Large appreciation of Yen relative to US dollar related to closing of "yen carry trades".
	Oct. 14th: BankAmerica reports 78% fall in earnings
	Oct. 15th: Federal Reserve cuts rate between meetings
IV. Oct.16th – 31st Dec.	Cooling down
	Nov. 13th: Brazil formally requests IMF programme
	Nov. 17th: Federal Reserve cuts rates
	Dec. 2nd: IMF Board approves programme for Brazil
	Dec.3rd: Coordinated rate cut by European central banks

Source: BIS (1999)

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