THE INFORMATION CONTENT OF THE EURO-BUND FUTURES OPTION MARKETS

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Abstract

Most recent empirical literature focuses on the information content of option volume for future security price movements. Few of these studies explore the possibility that there is information content in the option order book about the underlying security's future price movements. This dissertation explores this possibility. We first find that the book imbalance defined as scaled difference between asked size and bid size at the best limit price levels in the Euro-Bund futures option order book is significantly related to short-term its futures returns only for Euro-Bund futures at-the-money (ATM) options. However, book imbalances beyond the best price levels are not informative to the Euro-Bund futures price movements. We further document that, when trading cost, measured by the bid-ask spread, is relatively high (more than 3 ticks), there is no price discovery from the Euro-Bund futures ATM option market to the Euro-Bund futures market. However, when the trading cost is relatively low (less than 2 ticks), information in the Euro-Bund futures ATM option market is associated with its futures returns. Finally, we show that Euro-Bund futures ATM put options are more informative than its ATM call for the underlying futures price formation in periods with more negative news surprises regarding interest rate risks. The dominance of Euro-Bund futures ATM put options is mainly due to market environments. This is consistent with the notion that traders seek protection against downside of interest rate risk by buying puts rather than selling calls in periods with more negative news surprises regarding interest rate risks.

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1 Introduction

The process of discovering the fundamental value of a security among its relevant markets is known as price discovery and is one of the most important functions of an exchange. Since the suggestion of Black (1975) that the higher leverage in option markets may attract informed traders to trade in these markets, this conjecture has inspired a voluminous research investigating derivative markets as a venue for information-based trading. Efforts to evaluate this issue have led to the development of an extensive market microstructure literature on equity markets and its related derivative markets (Easley et al., 1998; Pan and Poteshman, 2006; Collver, 2009; Chakravarty et al., 2004), and between commodity futures and futures options (Evans and Mahoney, 1996, 1997; Hall et al., 2006).

However, there is a silence on price discovery in interest rate derivatives markets about how interest rate futures option markets contribute to price discovery of the underlying futures markets. This could be due to the fact that the underlying futures are already leveraged through the margin requirement, being initial margin of 3 to 5% of notional amount of transaction. Combining this fact with the high liquidity in futures markets, traders may prefer trading in the interest rate futures market rather than the associated options market. However, at Eurex the Euro-Bund futures options are margined futures-style, which provides additional leverage benefits for the futures options. This offsetting characteristic allows us to explore the possibility of price discovery across these two markets.

This is especially interesting for the interest rate derivative markets providing a compelling case since these markets are mainly driven by the release of public information[1] in

[1] Public information is strictly defined as information that affects security prices before anyone can trade on it (French and Roll, 1986)

the form of macroeconomic news announcements. At the first glance, it seems unlikely that the information content of trades and quotes in the interest rate futures option markets would be strongly associated with its underlying futures price movements because no one can have the public information before its announcement. However, recent literature (Fleming and Remonola, 1999; Green, 2004; Brandt and Kavajecz, 2004; among others) on government security markets shows that investors can gain an advantage from superior information processing skills, for example having a better interpretation on the impact of a news surprise on interest rate movements. Therefore, the relevant question is how and in which market traders use this advantage.

Most of recent literature focuses on the information content of option trading volume for future price movements. Few studies explore the possibility that the information content embedded in the order book is related to the underlying security's future price movements, although there is recent empirical evidence showing a security's order book is informative to its price formation in equity markets (Harris and Panchapagesan, 2005; Cao et al., 2009; among others). This dissertation explores this possibility in interest rate futures options by looking at the information content of the order book in futures options. By using data on the Euro-Bund futures and futures option in first six months of 2007, we study whether book imbalances in the futures option market are associated with the underlying futures price movements. We employ principal component analysis to extract a common measure for order book imbalances to explore this topic.

There are several main findings in this dissertation. First, the book imbalance-defined as the scaled difference between asked size and bid size at the best limit price levels in the Euro-Bund futures option order book-is significantly related to short-term its futures returns only for at-the-money (ATM) options, but not for Euro-Bund futures options with other moneyness (out-of-the-money or in-the-money). We further explore the information content of book imbalances beyond the best price levels in Euro-Bund futures ATM option markets and show that book imbalances beyond the best price levels are not informative. It is likely that this finding is due to the relative trading cost measured by the bid-ask spread between Euro-Bund futures and futures ATM option markets.

We further explore the tradeoff between leverage and relative trading cost in the Euro-Bund futures ATM option markets to its futures market. We document that the Euro-Bund futures ATM options dominate options away from at the money in trading volume and it has relatively low bid-ask spread. We divide the Euro-Bund futures ATM option sample into two subsamples. One is data with average bid-ask spread below two ticks (just below mean value of bid-ask spread of Euro-Bund futures ATM options). The other is data with more than three ticks of bid-ask spread, which denotes periods with relatively high trading cost. We find, when trading cost is relatively high, there is little or no price discovery from the Euro-Bund futures ATM option markets to the Euro-Bund futures market. However, when the trading cost is relatively low, the information content of book imbalance in the futures ATM option order book is informative to its futures price movements. Therefore, leverage of futures options and relative trading cost in the Euro-Bund futures ATM option markets to its futures market play an important role in price discovery from Euro-Bund futures option markets to its futures markets.

Finally, we show that the information content in the order book of the Euro-Bund futures ATM options for its futures price is very sensitive to market environments. We divide the Euro-Bund futures ATM option sample into two subsamples. One is data with little negative news surprises regarding interest rate risk. The other is data with more negative news surprises regarding interest rate risk. We find that the book imbalance of Euro-Bund futures ATM put option is only informative to Euro-Bund futures price movements in the sample with more negative news surprise regarding interest rate risk. Therefore, there is clear evidence showing that during periods with negative news surprises, Euro-Bund futures ATM put options play an important role in price formation of Euro-Bund futures. This is consistent with the notion that traders seek protection against downside of interest rate risk by buying puts rather than selling calls when they expect that interest rates will rise in the future.

The dissertation contributes to the literature in several ways. First, to our knowledge, this is the first paper examining the information content of book imbalance impact in the interest rate futures option order book on the related futures contract price movement. We extend the literature from the information content of option-volume at the transaction level to the information content at the order level. This dissertation shows that the book imbalance of the Euro-Bund futures ATM option order book is strongly related to its futures price movements. Thus, the study fills the gap by adding this direct empirical evidence.

The second contribution is from our unique data set extracted from the Eurex historical order book. It provides a more accurate net trade volume through a direct way to identify a trade direction. By combining two indicators in trade data, one showing whether an order is a buying or a selling order and the other showing whether a trade is an aggressive or a passive trade, we are able to completely identify the trade direction for each trade in the sample. As a result, it reduces the measurement errors of our controlled variables. The results from our analysis are more accurate than those that rely on indirect methods to identify the trade direction (Odders-White, 2000; Bessembinder, 2003; among others). Moreover, all orders and trades were recorded at the 10-millisecond level in the Eurex historical order book. This allows us to construct the order book for each product in high frequency during the sample period. As a result, it allows more exploration of the full information content of the order book.

Finally, the findings in this dissertation have important implications in practice. We find that the information content of the order book imbalance in Euro-Bund futures ATM option markets is strongly associated with its futures returns. The relation is much stronger in periods associated with high interest rate risks. These findings may help market makers in the interest rate futures option markets manage information asymmetry risk. It is relevant to market makers in futures option markets to hedge their positions by watching for signals about future price movement of interest rate futures.

The rest of dissertation is organized as follows. The second section reviews the theoretical and empirical literature and provide hypothesis on the research question. The third section describes the Euro-Bund futures and futures options markets, and details on the construction of the data set. The next section provides the research methodology employed in empirical analysis. The fifth section discusses empirical findings and implications, and the final section offers concluding remarks.

2 Literature Review

In this section we first review the theoretical links between Euro-Bund futures and futures option markets based on the extension of a model in Easley et al. (1998). Basically, we incorporate book imbalance from the recent public limit order book literature into the theoretical discussion in order to show a link between order imbalance in option markets and their underlying futures price movement. Then we present recent relevant empirical evidence, and draw our testing hypothesis based on these discussions.

2.1 Theoretical discussion

Since the claim of Black (1975), Easley, O'Hara, and Srinivas (1998) demonstrate a theoretical model showing that the levels of leverage from options with different moneyness play an important role in determining the flow of information regarding the value of the underlying asset if informed traders choose to trade in both equity and equity options markets. The definition of informed traders in their model is based on private information, which is quite plausible in equity markets, but quite questionable in government security markets (Hasbrouck, 2006).

Price movements in government security markets are mainly driven by dispersed beliefs on what new public information means for true prices (Fleming and Remolona, 1999; Pasquariello and Vega, 2007). Traders have an advantage in trading if they have better processing skills or better knowledge about how to value new public information: for example, the skill, which can be a valuation model quantifying new public information in a more accurate way, or knowledge about the interpretation from a person who understands contents of new public information better. In this sense, we defined trading is "informed" if it discloses the direction of subsequent price change. In the following, we restate the theoretical model in Easley et al. (1998) in order to accommodate our definition of "informed."

In a sequential trade model like Glosten and Milgrom (1985) there are risk-neutral competitive market makers who face two types of investors. One is defined as smart traders, who have valuation advantages over others in terms of their skills or knowledge about how to interpret new information in government security markets. The other is classified as liquidity traders, who are in the market for liquidity reasons. These market makers watch both the interest rate futures and futures option markets[2] and set prices such that the expected profit on any trade is zero, conditional on futures or futures options being traded. Liquidity traders are assumed to trade in both interest rate futures and futures option markets. Smart traders can choose to buy or sell interest rate futures, buy or sell interest rate futures call options, or buy or sell interest rate futures put options. The choice among futures, futures call, or futures put depends on profit from the respective trade.

Following Easley et al. (1998), there are two types of equilibria. In a "separating equilibrium" smart traders will only trade in the futures market because it is more liquid, with low transaction cost while the futures option market has low liquidity, therefore, high trading costs. In this case, only positive futures net trade volume signal favorable news and will be accompanied by upward revisions of the futures price. However, the futures option trading conveys little information about the futures price.

In a "pooling equilibrium" smart traders trade in both interest rate futures and futures option markets, and therefore the futures option trading could convey information about futures price movements. In particular, buying a futures call or selling a futures put provides a favorable

[2]In this dissertation, market makers not only watch market from the order book, they also watch the OTC market if data are available or if they are one of counterparties involved in the OTC transaction.

signal about the futures price to all traders, while selling a futures call or buying a futures put conveys an unfavorable signal on futures price to all traders. For example, positive futures put net trade volume carries unfavorable news on the futures price; therefore, futures put net trade volume is negatively related to the futures price movement, while positive futures call net trade volume conveys favorable news. As a result, positive call net trade volume is positively associated with futures return.

They also note that this prediction may have a multidimensional structure based on different levels of leverage offered by futures options. Option theory suggests that options with different moneyness offer different degrees of leverage. Out-of-the-money (OTM) options have the highest level of leverage, followed by at-the-money (ATM), and in-the-money (ITM) options with lowest level of leverage. However, the bid-ask spread tends to be lowest for ATM options compared to OTM and ITM options. Therefore, smart traders can increase their returns by using high leverage options as long as the trading profits is higher than transaction costs associated with using this type of futures option. Therefore, not just net trade volume from a call or a put but rather from options with varying levels of leverages play an important role in determining the flow of information regarding the futures price if smart traders choose to trade in both futures and futures option markets.

In this model, it is assumed that smart traders prefer using market orders. Therefore, there is a strong relation between net trade volume and the interest rate futures price. In practice, however, smart traders could submit either market orders or limit orders to exploit their advantages of knowledge on new public information. If the value of their advantages in this case is less than the bid-ask spread, smart investors would either not to trade or submit limit orders instead. Otherwise, they have to pay the bid-ask spread if they submit market orders. This could be an especially important consideration for the interest rate futures option market because we always observe that the proportional bid-ask spread in terms of its price is relatively large in the market. Thus it simply depends on smart investors' order placement strategies. If they use market orders, net trade volume in the futures option markets will be informative to the underlying futures price formation. If they decide to use limit orders, their advantage on how to incorporate public information into government security prices may be reflected in the public limit order book. Kaniel and Liu (2006) also point out that smart traders may prefer using limit orders because submitting market orders signals impatience and reveals too much information to other traders.

If smart traders prefer limit over market orders, then the information in the public limit order book in interest rate futures option markets can provide another valuable signal to interest rate futures price movement. A limit order book presents a picture of the potential market demand and supply at a given point of time. If there is a book imbalance in the way that the cumulative order size on the supply side is greater than that on the demand side, or the cumulative order size on the demand side is greater than that on the supply side, it may signal a movement of security price in next time interval (Cao et al., 2009; Foucault, 1999; Hollifield et al., 2004; Ranaldo, 2004). Harris (1990) shows that a book imbalance caused by the presence of value-motivated traders will disclose their valuations on future price. In this sense, the book imbalance carries a signal on future price movements.

If there is more supply than demand sitting in the interest rate futures call option order book, it may signal that the futures call price tends to move lower. Because large order sizes on the ask side will encourage more market sell orders of the futures call option. These markets sell orders will consume the liquidity sitting on the bid side of the futures call option order book. As a result, the futures call price expects to move downward. This may send an unfavorable signal on the underlying interest rate futures price because, other things held constant, there is positive relation between the interest rate futures and futures call option prices.. As a result, more supply than demand sitting on interest rate call option order book signals a lower value of interest rate futures price.

However, if there are more supply than demand placing in the interest rate futures put option order book, it is a favorable signal on the underlying futures price movement. More supply than demand in the futures option order book tends to lower the futures put price because a futures put price is negatively associated with the underlying futures price. In this case, the futures put option book imbalance will be positively associated with future short-term futures returns. If the futures put book imbalance shows in the way that the demand of futures put is more than the supply, then it is negatively related to future short-term futures returns.

Moreover, market makers in the interest rate futures option markets have needs of hedging their positions over time. Therefore, their needs to hedge could also bring an informational link between interest rate futures and futures option markets. Vijh (1990) points out that option investors are more probably in a long position rather than in a short position, and market makers are more likely to be writers of options. Since the risks of writing options are much higher than holding them, market makers have needs to hedge their call or put positions. Therefore, subsequent to public purchases of futures call or put option, there may be an increase in buying or selling the underlying futures. If the initial purchase of the futures call or put option is from smart investors, then this hedging behavior could also help create an informational linkage from the interest rate futures option market to the interest rate futures market.

Under our specific interest rate future option market setting, traders are allowed to use the OTC block transactions to hide their purpose of transactions. The OTC block trade facility allows them to disclose their transaction after markets close. This may bring additional linkage from smarter traders to make trades in futures option markets. If a market marker is the counterparty of transaction with a smart investor, then the market maker is able to instantaneously infer that the probability of change in the underlying futures price is high after this transaction. She can immediately adjust her quotes on both sides of the order book. In order to accommodate he adverse selection risk observed, she can either choose to increase her bid-ask spread or to adjust the demand and the supply of futures options. If she decides to increase the bid-ask spread, the limit prices that she posts will not become the best prices any more in the order book because other market makers may not follow her since they don't have the same information as she does. In this case she loses her advantage in market making. If she decides to adjust her quote sizes, then it mainly depends on whether the signal she receives is positive or negative.

If smart investors purchase a future call option from one of the market makers, the purchase of the futures call is a favorable signal to the futures price movement. The market maker can increase the call option quote size on the bid side and/or reduce of the quote size on the ask side, leading to a book imbalance with more demand than supply of the futures call. Or she can increase the put option quote size on the ask side and/or reduce the quote size on the bid side, resulting in a book imbalance with more supply than demand of the future put. In either case, the book imbalance will signal a movement of futures price.

Therefore, we argue that there may be a signal from the order book that can convey information about the underlying asset price movements. Mann and Ramanlal (1996) argue that the quote size in the order book is a more informative indicator of market liquidity than the adverse selection component of bid-ask spread because the imbalance between the supply and the demand in the order book reflects the private information that cannot be inferred from the bid-ask spread. This suggests that the book imbalance in the option order book may be an additional candidate which can be used to infer a signal regarding the underlying futures price movements. Therefore, in this dissertation we mainly investigate the informational role of book imbalance in the interest rate option order book for the underlying futures price movements.

2.2. Empirical literature

Since this dissertation combines three lines of literature, the price-volume relation in equity and equity derivative markets, order flow contribution to price formation in interest rate derivative, and order imbalance in a public limit order book in equity markets, we only concentrate on empirical evidence with a focus on insights that are directly relevant for our empirical study.

First, most literature tests the model from Easley et al. (1998) based on volume related variables in the equity market. The empirical evidence is mixed. There are different arguments about whether option volume contributes to price discovery of the underlying asset. On one hand, a number of papers using different measures of option volume find that option volume contains information of the underlying asset value. Pan and Poteshman (2006) find put-call ratios generated from buyer-initiated new option positions can affect the future stock return. Cao et al. (2005) document that, during pre-announcement period, call option net trade volume is positively associated with next-day stock return in a sample of target firms. Amin and Lee (1997) study a sample of firms with good and bad earning news and find that a larger portion of long (short) position is taken in the option market before the announcement of the news. On the other hand, Easley et al. (1998) report that net option trade volume only contains more information about contemporaneous stock prices but little about future stock return. Chan et al. (2002) show that net option trade volume does not lead stock prices. Cao et al. (2005) also found net option trade volume is not informative about future stock price movement at normal time.

Moreover, there is also a debate on how different levels of leverage affect traders to choose a venue of trading for their information about the value of the underlying asset. Some studies find that informed traders in the equity market tend to use OTM options. Cao et al. (2005) find that returns on trading triggered by a signal from short-term OTM call net trade volume are more statistically and economically significant than those generated from ATM and ITM call net trade volume before merger announcement. Pan and Poteshman (2006) find that high leveraged OTM equity options have the largest level of predictability on stock returns through the signal from put-call ratios generated from buyer-initiated new options positions. Others argue that ATM or ITM options may be more important to informed traders in equity market (de Jong et al., 2001; Kaul et al., 2002). For example, de Jong et al. (2001) suggest that insiders in the equity market may favor ITM options because the more intrinsic value of an option, the greater tendency for insiders to trade in the option markets. However, Anand and Chakravarty (2007) argue that the place informed traders in the equity market choose to trade depends on leverage and the underlying liquidity of the option contract. Chakravarty et al. (2004) empirically document that price discovery from equity options to the underlying equity market tends to be higher where trading volume is high and bid-ask spreads are narrow.

Secondly, the important role of trade volume or net trade volume in the U.S. Treasury Security futures markets has also been documented by recent studies. Menkveld et al. (2006) report that customer net trade volume is a significant explanatory variable in daily return of 30-year Treasury bond futures. Brandt et al. (2007) find net trade volume drives movements of the

U.S. Treasury security futures markets. Holder et al. (2004) find that net trade volume significantly impacts the U.S. 10-year T-Notes futures return.

Thirdly, the importance of the book imbalance in price formation in the open limit order book has been found in recent literature. Huang and Stoll (1994) report that differences in quote sizes between the bid and asked sides lead stock price changes in the short run. Harris and Panchapagesan (2005) use order quantities in the book to investigate whether specialists in NYSE have information advantage on price formation when they compete with limit order traders. They find that the book information favors specialists. Cao et al. (2009) examine book information regarding the number of shares quoted at each price step and price distance among these price steps. They find that the book imbalances between the supply and demand schedules across the order book are significantly associated with future short-term returns.

The empirical evidence from these three lines of literature, combined with theoretical projection discussed in the previous section, strongly suggest that net trade volume and the book imbalances in Euro-Bund futures option markets may be strongly related to Euro-Bund futures price formation. However, no empirical evidence shows that information content in the interest rate futures option order book is strongly associated with the interest rate futures price movements. In this dissertation we empirically explore this possibility. We form the following hypothesis:

Hypothesis: Book imbalances in the Euro-Bund futures option order book are significantly related to Euro-Bund futures price movements.

A rejection of the hypothesis indicates that book imbalances in the Euro-Bund futures option order book are not informative for short-term Euro-Bund futures price movements. To test this hypothesis, we employ principle component analysis to extract a common measure for the demand and supply imbalance in the Euro-Bund futures and futures option order book. Next, we turn to the discussion of markets of interest.

3 Data

In this section we first present markets of interest, Euro-Bund futures and futures options markets. Then, we discuss how to construct dataset from Eurex historical order book data. Finally, we present some descriptive information regarding the sample used in the dissertation.

3.1. Euro-Bund futures and futures option markets

The markets of interest in this dissertation are Euro-Bund futures and futures options markets. The Euro-Bund products serve as the benchmark for the European yield curve and a standard reference when comparing, evaluating and hedging interest rate risks in Europe. Therefore, it is very important to understand how information flows between Euro-Bund derivatives markets.

The Euro-Bund futures market is based on a notional German government security with a fixed coupon of six percent and a remaining lifetime between 8.5 and 10.5 years at the date of delivery. Normally, a number of government securities issues, which can be on-the-run or off-the-run, are available for fulfilling the delivery obligation. The price of Euro-Bund futures is quoted in percent of the nominal value of the notional bond to two decimal places. The nominal value of a Euro-Bund futures contract is EUR 100,000. That is, one Euro-Bund futures contract is for the delivery of EUR 100,000 of a German government security with the remaining years of 8.5 to 10.5 years. The minimum price movement is 0.01 percent, one tick. The corresponding value of one tick is EUR 10. The Euro-Bund futures contract months are always the three nearest quarterly months of the March, June, September, and December cycle. The regular trading hours for Euro-Bund futures are between 8:00 and 20:00 Central European Time (CET).

Eurex not only offers Euro-Bund futures but also their options. The Euro-Bund futures option markets provide another venue for rebalancing and hedging portfolio risk or for improving portfolio return. These options are American-style with regularly trading hours between 8:00 and 19:00 CET, and have a different profile than the corresponding futures. Buying one contract of Euro-Bund futures option gives the option holder the right, but not the obligation, to either buy or sell one contract of the underlying Euro-Bund futures at a predetermined price on any exchange trading days throughout the lifetime of the option. For example, if the buyer of one contract of the Euro-Bund futures call option exercises her right, she will buy one contract of Euro-Bund futures with specific maturity at the exercise price of the option, resulting in the opening of a long position of the underlying Euro-Bund futures. In order to have the right, the option buyer has to pay the option premium. The premium is settled by using future-style premium posting approach. A futures-style premium posting method states that the buyer of options pays the premium at exercise or at the expiration date of the option. Any change in option premium during the lifetime of the option is marked to market through variation margin, just as with futures. Therefore, the full premium is paid by option holders when the option is exercised. With this futures-style premium, Euro-Bund futures options offer much larger leverage than Euro-Bund futures. At least nine exercise prices for each call and put in each monthly series are available for trading. The contract months for these options are always the three successive calendar months from now on, as well as the following month within the March, June, September and December cycle. Euro-Bund futures option contracts have the same minimum price movement as Euro-Bund futures contracts.

The market participants in Euro-Bund futures and futures option markets include end customers, the brokers and market makers. End customers include hedgers and speculators.

Hedgers are insurers and funds, who are looking to lock in interest rates until the next futures rolls. Speculators are mainly from hedge funds and investment banks' proprietary trading desks. Brokers execute client business in Euro-Bund products by means of telephone brokerage or execution on behalf of a client in public order books. In addition, most brokers have developed electronic order routing solutions or online trading platforms to provide institutional and retail clients with direct market access to Euro-Bund products.

Table 1 shows market share per account group in the sample period. The market shares of three groups of market participants in Euro-Bund futures market are different in its option markets. Trading for clients accounts for 53.20% of market share, followed by proprietary trading with 36.42% and market maker with the rest of 10.38%. However, in the Euro-Bund futures option markets, trading from the agent group account dominates other two groups, with a market share of 77.67%. The share for market makers is 17.73% while the proprietary trading only accounts for 4.60%.

Table 1: Market share per account group (%)

	Agent	Proprietary	Market Maker
Euro-Bund Futures	53.20%	36.42%	10.38%
Options on Euro-Bund Futures	77.67%	4.60%	17.73%

Figures 1 and 2 show the transaction volume distribution for Euro-Bund futures and futures options markets in the first half of 2007. It is obvious that Euro-Bund futures are mainly order-driven market while its option markets use both order-driven and the OTC facilities. About 97.08% of trades in the Euro-Bund futures market are made in the order-driven trading system, while only 31.15% of trades in its option markets are executed in the order-drive trading system. The rest are placed in its OTC market.

Figure 1: Trading Volume Distribution of Euro-Bund Futures

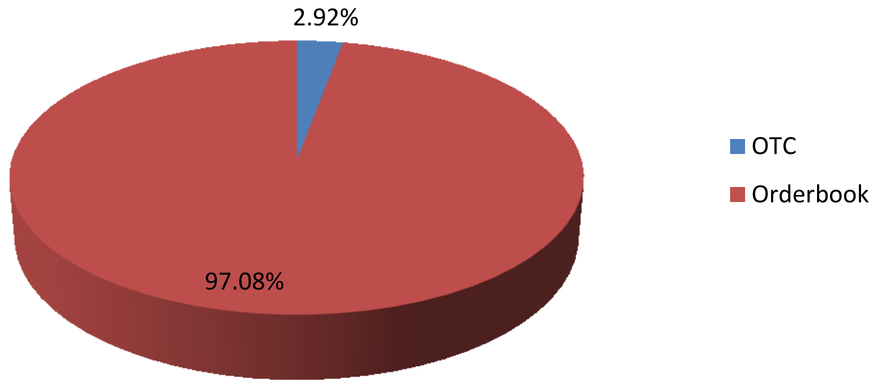
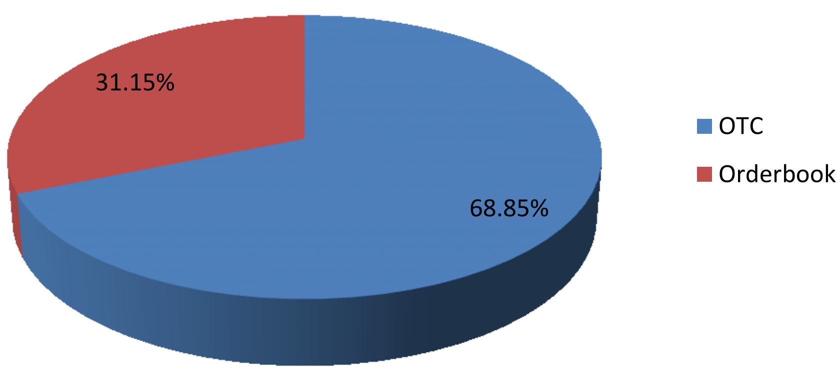


Figure 2: Trading Volume Distribution of Euro-Bund Futures Options



In the OTC market, the market participants can arrange their block trade by phone in a secret way. The block trade is defined as a trade with transaction volume greater than 50 Euro-Bund futures option contracts. Only two parties involved in the transaction know the information about the deal. These two parties can be brokers and/or market makers. Once the deal is made, two parties in the OTC transaction are not required to disclose their transaction immediately. They can request that all information regarding the transaction remain non-disclosed by using a non-disclosure facility until the close of markets. Therefore, they basically can arrange the block trade during the trading day but feed it into the system after markets close.

This type of practice may underestimate our findings in this dissertation. If we find no contribution of the Euro-Bund futures option markets to price formation in its futures market, obviously we cannot claim that there is no price discovery from the order book in the Euro-Bund futures option markets to its futures market. However, if we find certain contribution of the Euro-Bund futures option markets to price formation in its futures market, then it provides strong evidence that the information content in the Euro-Bund futures option order book is associated with its futures price formation.

The OTC facility for the block trade may also provide a way to disclose price formation process for the Euro-Bund futures. If a market maker is involved in the transaction with smart investors, she can update her beliefs by calculating the probabilities the futures value is lower or higher than her previous estimates conditional on whether the transaction is a buy or a sell of futures call or put. As a result, she can update her order book immediately. If smart investors make transactions with brokers or other market participants, then these counterparties can update their belief on valuation of the futures. If it deviates from their prior estimates, they can use it to make a trading decision, either adjusting their quotes or making trades. It really depends on the place they choose to trade because the futures, futures call or put markets have different transaction costs and levels of leverages. As Eastley et al. (1998) argue, options trade will be more informative to the underlying asset market even if only a small portion of informed investors choose to trade in option markets. This argument can also be applied here.

3.2. Sample

Data on Euro-Bund futures and futures options are extracted from the Eurex historical order book. The Eurex historical order book provides historical details of all orders placed in Eurex electronic trading system as well as any of its resulting trades at a frequency of 10 milliseconds. The information regarding trades and orders is recorded in the order intervals and trade file. By using transaction type indicating trades or orders, we can easily separate trades from orders.

After separation, information about trades contains product ID, which can be used to identify a derivative product, an indicator showing whether it is a call, a put or a futures contract; expiration month; an indicator showing whether it is a buying or selling order, an indicator showing whether it is a combination order from a strategic trading; the trading price; the trading timestamp; number of contracts traded, and number of executions; and an indicator showing it is an aggressive trade or a passive trade.

The advantage of information in trade data is to provide a more accurate way to identify whether a trade is initiated by a buyer or a seller. Basically, we combine two indicators in trade data, one showing whether an order is a buying or a selling order and the other showing whether a trade is an aggressive or a passive trade. A passive order rests in the order book and supplies liquidity while an aggressive order removes liquidity out of the order book by trading away passive orders. Thus, we are able to completely identify trade direction for each trade in the sample. This trade direction is very crucial because we need it to calculate net trade volume from transactions. The more accurate net trade volume, the more robust our findings. There is plenty of empirical evidence showing that a trade direction, which is identified by using algorithms from Lee and Ready (1991) and Ellis, Michealy, and O'Hara (2000) or a tick test (Holthausen et al. (1987)), contains measurement error. Lee and Ready (1991), Odders-White (2000), and Bessembinder (2003), and others show that the measurement error significantly affects accuracy in the calculation of net trade volume.

Information regarding orders contains product identification, an indicator showing whether it is a call, a put or a futures contract, expiration month, an indicator showing whether it is a buying or selling order, and indicators showing whether it is a combination order from a strategic trading. It also includes order price, order size, number of orders accumulated at the given order price, the starting timestamp, the ending timestamp, and interval length from the starting timestamp to ending timestamp measured in 10 milliseconds.

The main advantage regarding the information in the order book is to allow for the construction of the order book for each product at any point of time during the sample period. With the starting and ending timestamps we can easily select all records available at the specific point of in time following between them. Then we group them into buying or selling orders. For buying orders the limit prices are selected in ascending order, and for selling orders the limit prices are chosen in descending order. The corresponding order size at each limit price is selected accordingly. Table 2 provides a snapshot of reconstruction of the order book for Euro-Bund futures at 9:01 am on January 2, 2007, which mimics what traders can see from the screen in reality.

The reconstruction of Eurex historical order book suits our research question very well because it allows us to investigate how traders forwardly analyze the order book after controlling for the impact of trade when they can see information related to potential demand and supply in the Euro-Bund futures option markets. In the reconstructed dataset we have information about limit prices and their corresponding outstanding contracts at each price level up to 10 steps from the best bid and asked quotes for Euro-Bund futures and futures options.

Table 2 : A Snapshot of Order Book for Euro-Bund Futures at 1/2/2007 9:01 AM

Bid Size (contracts)	Limit Price	Ask Size (contracts)
	116.51	1043
	116.50	766
	116.49	724
	116.48	742
	116.47	2447
	116.46	1402
	116.45	1687
	116.44	1411
	116.43	730
	116.42	414
284	116.41	
1004	116.40	
700	116.39	
1769	116.38	
1036	116.37	
1018	116.36	
764	116.35	
829	116.34	
676	116.33	
1747	116.32	
1747	116.32	

Our data in this dissertation cover the period from January 02, 2007 to June 30, 2007. We follow Pascual and Veredas (2008) by sampling our data in one-minute time intervals because they show that the limit order book is more informative at one-minute than five-minute levels. We also find that the one-minute frequency strikes the balance between a larger number of observations and the need to allow meaningful changes in the security prices from any two subsequent time intervals since transactions in Euro-Bund futures option markets are less active than those in the Euro-Bund futures market. Even in the Euro-Bund futures market, we find about 40% of one-minute returns on the front month Euro-Bund futures are zeros. If we reconstruct the order book in higher frequency level, we suspect returns at that frequency will be dominated by zeros. All data are filtered as follows.

1) Since Euro-Bund futures and futures options are more liquid in the front month than any other back months, we restrict our study on the front month futures and futures options. This leaves us 101 trading days in the first half year of 2007.
2) In order to avoid confounding effects from the opening and pre-close procedures, we remove all trades and quotes with the timestamps arriving one hour after the opening and one hour before the closing of the regular trading hours in the Euro-Bund futures option markets. Therefore we restrict our study to the normal trading period from 9:00 to 18:00 CET.
3) We require that all observations with the bid price of Euro-Bund futures options must be greater than one tick, 0.01, because one-tick bid prices are considered uninformative and unreliable.
4) We remove all data with zero or negative bid-ask spread from Euro-Bund futures and futures option markets.
5) However, we also remove all data out of the restrictions on the maximum bid-ask spread since there are no abnormal events in the sample period. The maximum bid-ask spread is 0.03 index point for a bid range between 0 and 0.09 index point; 0.04 for a range between

0.1 and 0.29; 0.06 for a range between 0.3 and 1; and 0.08 for a range between 1.01 and 999.99[3].

After the data cleaning, we match all data based on the calendar clock (Chan et. al., 2002) because we need to align different markets based on the calendar clock in order to study price discovery in these two Euro-Bund derivatives markets. We then create variables of interest. First, for one-minute return, we first calculate the mid-quote futures price for each minute in the sample. Then one-minute return is just the log difference in the mid-quote futures prices between the beginning and end of each minute interval.

Secondly, net trade volume is chosen as a control variable in our study and is defined as buyer-initiated trade volume minus the seller-initiated trade volume within one minute interval. The inclusion of this variable is motivated by recent empirical evidence that net trade volume (order flow) in the U.S. Treasury futures markets is significantly associated with futures price movement (Menkveld et al., 2006; Mizrach and Neely, 2007; Brandt et. al., 2007; among others) and that net trade volume in the equity option market is strongly related to equity price movements (Cao et al, 2005; Pan and Poteshman, 2006; among others). Since we know the trade direction, which we set 1 for buyer and −1 for seller, we can multiply the trade direction by trade size in each trade in order to obtain buyer- or seller-initiated trade volumes. Then we sum up these signed trade volumes taking place within one-minute interval preceding that minute to come up with net trade volume at that minute.

The third variable is the book imbalance, which is our primary interest. The book imbalances in this dissertation are the quote size imbalances indicating quantity imbalance between the supply and demand on both bid and ask sides of an order book. Empirical evidence (Cao et al.,

[3] Only less than 0.01 percent of observations are eliminated from the sample.

2009) shows that there is strong relation between lagged quantity imbalances between the supply and the demand sitting in the equity limit order book and future equity return. We use two measures for the book imbalances. One is measured by the common factor from the principle component analysis. We first calculate the cumulative quote sizes up to each step from 1 to 10 on both bid and asked sides of the order book. In this case, we construct 20 variables to measure cumulative quote sizes in the book. Then we perform the principle component analysis to identify one common factor that is able to measure quote imbalances across the selected spectrum of the order book. The details for construction of order imbalances across 10 steps of the order book by using the principal component analysis will be discussed in the next methodology subsection.

In order to compare our one common measure for the book imbalance between supply and demand schedules across an order book with existing ones, we follow Cao et al. (2009) to construct a step-wised scaled quote size imbalance at each step of the order book. Specifically, for step j of order book, the order imbalance is measured by the following equation.

$$OI_j = \frac{S_j^A - S_j^B}{S_j^A + S_j^{B,}} \text{ }, j = 1, 2, \ldots, 10 \qquad \ldots \ldots \qquad (1)$$

Where S_j^A and S_j^B are the jth step ask and bid sizes in the order book. Intuitively, OI_j can be explained as the step-wised imbalance between the demand and the supply schedules at step j in the order book. The positive value of OI_j indicates more supply than demand at step j of the order book, while the negative value of OIs represents more demand than supply at step j of the order book. Economically, a large order size at the ask side of the book encourages more market sell orders. These market sell orders take liquidity sitting on the bid side of the order book. As a result, it expects to drive the futures price lower. Similarly, a large order size at the bid side of the order book may encourage more market buy orders. These market buy orders take limit orders on the ask side of the order book, leading to a higher futures price (Parlour, 1998; Foucault, 1999; among others).

Motivated by theory and empirical evidence (Easley et al., 1998; Chan et al., 2002; Pan and Poteshman, 2006; among others), the leverage of an option is a key factor which determines where investors choose to trade in the option market. We partition the full sample into three different subsamples. These are out-of-the-money (OTM), at-the-money (ATM), and in-the-money (ITM) samples. We define the moneyness as the mid-quote futures price divided by exercise price of an option. We classify all futures options within two strike prices of the current Euro-Bund futures price as the ATM options. It roughly corresponds to the range of moneyness between 0.991 and 1.008. All futures call options with more than two strike prices above the mid-quote futures price and all futures put options with more than two strike prices below the mid-quote futures price are classified as futures OTM options. The rest are futures ITM options. The classification of moneyenss for Euro-Bund futures options is totally different with equity options markets, in which moneyness is normally cut off at 0.95 and 1.05. This chosen classification in Euro-Bund futures options markets takes Euro-Bund futures market characteristics into account. In the sample, we calculate high-minus-low futures price as the difference between intraday highest and lowest Euro-Bund futures prices over the sample period. We find the mean value of this high-minus-low futures price is 0.4, which is 0.35% of the mean mid-quote futures price, 114.14, shown in Table 3. Moreover, 0.4 of high-minus-low futures price is also less than 0.5, which is the increment of exercise price of Euro-Bund futures options at Eurex. Therefore, we are confident about our classification.[4]

3.3 Descriptive information

Table 3: Characteristics of Euro-Bund Futures and Futures Options				
	Mean	Std	Min	Max
Panel A: Euro-Bund Futures				
1-minute Return	-0.000001	0.000095	-0.00327	0.00118
Mid-quote Price	114.136	1.854	109.685	116.615
Bid-ask Spread	0.0101	0.0008	0.01	0.04
High-Low Price Change	0.4	0.135	0.15	0.8
Number of Contract	2082	2788	1	50216
Number of Trades	33	42	1	1461
Net Trade Volume	-16	1443	-21019	16375
Panel B: Euro-Bund Call Options				
Number of Contract	196	352	0	7100
Number of Trades	1.79	1.67	0	42
Net Trade Volume	-1.27	352	-3732	7100
Panel C: Euro-Bund Put Options				
Number of Contract	180	335	0	7350
Number of Trades	1.76	1.64	0	25
Net Trade Volume	13.83	318	-7350	3878

Table 3 provides summary statistics in the sample. Trading and quote activities in Euro-Bund futures markets are reported in Panel A. The mean one-minute return of Euro-Bund futures is -0.000001 with a standard deviation of 0.000095. The maximum downward movement of Euro-Bund futures price in one minute interval in terms of the mean mid-quote futures price, 114.136, in the sample is about -37 ticks. The maximum upward movement of one-minute futures price in terms of the average mid-quote futures price is 13.5 ticks. This shows certain volatility of futures returns in the data. This is confirmed by the range between the highest and lowest intraday

[4] We also asked persons working at Eurex about how to classify Euro-Bund futures options into the OTM, ATM, and ITM categories. They are comfortable with our classification.

futures price. The average range of high-minus-low futures price change is 40 ticks, with a maximum of 80 ticks and a minimum of 15 ticks. On average the Euro-Bund futures market always maintains one tick bid-ask spread with a maximum of four ticks. This shows futures markets are highly liquid. The high liquidity in the Euro-Bund futures market is confirmed by trading volume and number of trades. The average number of trading volume per minute is 2,082 contracts, with lowest 1contract and highest 50,216 contracts. The average number of trades per minute in my sample is 33 with a minimum of 1 and a maximum of 1461. The average order flow per minute in Euro-Bund futures market is −16, indicating that on average buyer-initiated volume is slightly less than seller-initiated volume in the sample period. Buyer-initiated volume outpaces seller-initiated volume with a maximum value of 16,375 contracts in a one-minute interval, while seller-initiated volume exceeds buyer-initiated volume with a maximum value of 16,375 contracts in a one-minute interval. It shows in some minutes trades are hugely imbalanced.

Euro-Bund futures options are less liquid than Euro-Bund futures in terms of trading volume and number of trades. The average numbers of trade contracts per minute are 196 for calls and 180 for puts, corresponding to 8.64% and 9.41% of Euro-Bund futures volume. In terms of number of trades, it is 1.79 per minute for call and 1.76 for puts. Comparing to 33 trades per minute in number of trades in the Euro-Bund futures market, both are far lower. It is obvious that two markets do not have the same liquidity. Since we are studying the information linkage between these two markets, we need to strike a balance when we reconstruct our dataset from the Eurex historical order book.

The average net trade volume per minute for Euro-Bund futures call options is -1.27, showing that buyer-initiated volume is less than the same as seller-initiated trades in the sample;

in other words, a few more people are selling Euro-Bund futures calls during the sample period. However, the minimum and maximum values of order flow show that there are strong variations of net trade volume. Buyers initiate more than 7,100 contracts of futures call options than sellers in one minute, while sellers initiate more than 3,732 contracts of futures call options than buyer within one of minutes.

The average net trade volume per minute for Euro-Bund futures put options is 13.83 contracts, accounting for 7.67% of its average trade contract. This shows that on average buyer-initiated put volume is more than seller-initiated put volume in the sample period. This is pretty stunning. It means that there are more Euro-Bund futures put option holders. Buyers initiate 3,873 contracts more than sellers in one minute, while sellers initiate 7,350 contracts more than buyers in one minute. It shows net trade volume per minute for Euro-Bund futures put options varies dramatically with a standard deviation of 318 contracts per minute.

Table 4: Number of Contracts Traded in Euro-Bund Future Options with Different Moneyness

	Total Volume	Buyer-Initiated	Seller-initiated
		CALL	
OTM	655,682	325,481	330,201
ATM	2,281,811	1,142,928	1,138,883
ITM	21,003	9,281	11,722
		PUT	
OTM	488,432	245,336	243,096
ATM	2,016,861	1,107,208	909,653
ITM	38,117	23,125	14,993

The first column in Table 4 shows the total number of contracts traded for Euro-Bund Futures options with different moneyness. Either for Euro-Bund futures call or put, trading at the futures ATM option dominates options with other moneyness. On average there are 2,016,861 traded contracts for futures ATM puts and 2,281,811 contracts for futures ATM calls, totally accounting for 78.13% of all trading volume in the sample. Trading in the futures OTM option market follows with 655,682 call contracts and 488,432. There is only a small portion of trades taken for the futures ITM options.

The trade volumes initiated by buyers and sellers for Euro-Bund futures options with different leverages are also shown in Table 4. Trade volumes are mainly concentrated in the Euro-Bund futures ATM option markets. The most impressive feature is that traders purchase more futures ATM and ITM put options than writing them in the sample. However, in terms of futures ATM call option, trades are quite balanced between buyer-initiated and seller-initiated transactions. Trades are also quite balanced for both futures OTM put and call options. It is only relatively unbalanced for the futures ITM call option. Traders write more calls than purchasing them in the sample.

4 Methodology

In this section, we mainly describe the research methodology used in this dissertation. The main research question in this dissertation is to investigate whether information embedded in the book imbalances from the order book of Euro-Bund futures option markets is associated with future Euro-Bund futures return. We first follow the standard procedure in literature to focus on the unexpected components in futures returns. We extract innovation in futures returns by running the following regression,

$$R_t^F = \sum_{i=1}^{p} a_i R_{t-i}^F + \sum_{j=1}^{p} b_i D_j \quad + \mu_{1,t} \quad \dots \dots \qquad (2)$$

where $R_{t,\tau}^F$ is the percentage change in the Euro-Bund futures mid-quote prices in the minute interval t, D_j is intraday hourly dummy from 9:00 to 18:00 CET, which is used to filter out the intraday seasonality (Ahn et. al., 2002), and p is the optimal number of lags for futures returns. The optimal lags of Euro-Bund futures returns will be determined by the Akaike Information Criterion.

The literature has shown that the book imbalance is associated with future price movements (Ranaldo, 2004; Harris and Panchapagesan, 2005; among others). However, because there are so many book imbalances across price steps of an order book, researchers have to make a choice on them. In this dissertation we use principal component analysis to extract one common factor (principal component) measuring the book imbalances across a specified spectrum of order book. Our approach is close to the one used in Beltran-Lopez et al. (2006). In their paper they study commonalities underlying the price impact from different trade volumes implied by the limit order book. In this dissertation, we focus on common factors based on order sizes in the order book, and statistically show that the second common factor from the principal component analysis is the one measuring the book imbalances across preselected levels of order prices in the order book.

The underlying assumption of principal component analysis is that quote sizes across the spectrum of limit bid and asked price levels can be summarized by a few common factors. These common factors account for most of the variance in order sizes across preselected price steps in the order book. Let's assume we choose the cumulative order sizes for N best limit prices on the bid and asked sides of the order book. Therefore we have 2N variables measuring the supply and demand schedule in the order book. These 2N cumulative order sizes are measured in a T×2N matrix X. T is the length of time series in the sample. The cumulative order sizes are expressed as a linear combination of 2N orthogonal vectors, called as common factors or principal components.

$$X = FZ'$$

where $F = (F_1, F_2, \ldots, F_{2N})$ denotes a T×2N matrix containing the orthogonal common factors , and Z is 2N×2N matrix of weights, which provides mapping between common factors and selected cumulative order sizes. The method first constructs the sample correlation matrix of cumulative order sizes, $\frac{X'\mathrm{X}}{\mathrm{T}}$. Then the eigenvalues and associated eigenvectors of the sample correlation matrix are computed. The columns of matrix Z contain these eigenvectors, which are arranged in descending order of associated eigenvalues. Finally, the common factors are computed as

$$F = XZ$$

The first principal component is the one explaining most of the variation in cumulative order sizes on selected first several steps in the order book. It is followed by the second principal components, and so forth. In this dissertation, we only select the first k principal components as long as the cumulative explanatory power of these common factors is equal to 90%.

If there is a commonality across the book imbalances at each price step on both bid and asked sizes in the order book, then we expect one of the principal components could explain a large portion of variation among these quote size imbalances across the preset spectrum of the order book. To test which principal component is the one with the most explanatory power on quote imbalances, we run a regression as the following.

$$F_j \; = \sum_{i=1}^{m} a_i OI_{i,t} + \varepsilon_{2,t} \quad \dots \dots \qquad (3)$$

where F_j is the jth common factor from principal component analysis, j=1,2, …k, and m is the selected steps of the order book. If one of the common factors can be largely explained by selected OIs, then this common factor is denoted as scaled quote imbalance common factor across the selected price steps of the order book. Moreover, sign of a_is show us how to explain F_j economically. If all or most of a_is are positive, F_j is interpreted the same as step-wise scaled quote size imbalances from equation (1). Otherwise, it has an opposite economic meaning to step-wise scaled quote imbalances from equation (1).

After identifying the common factor, F^*, which represents the book imbalances across the order book, we run the following regression in Euro-Bund futures markets in order to identify the optimal price steps, m, in the order book. The one with the highest adjusted R^2 will be chosen to determine m.

$$\mu_{1,t} = \beta_0 + \beta_1 OF_{[t-1,t)} + \beta_2 F^*_{t-1} + \varepsilon_{3,t} \quad \dots \dots \qquad (4)$$

where $OF_{[t-1,t)}$ is the net trade volume from trades from minute t-1 to t, and F^*_{t-1} is the common factor indicating order imbalance from selected steps across the Euro-Bund futures order book at the minute of t-1. In this model we expect β_1 to be positive because if there are more buyer-initiated than seller-initiated futures trade contracts between minute t-1 and t, then net trade volume in this case signals positive news on the fundamental value of futures, and will be associated with upward revision of futures price (Easley et al., 1998). We also expect $\beta_2$to be negative because the higher F^*, the more supply than demand in the order book, the lower futures price if F^* has the same economic meaning as QIs, vice versa (Foucault, 1999; among others).

Since we are interested in whether the book imbalances across the Euro-Bund futures option markets are strongly associated with future short-term Euro-Bund futures return, we next add quote imbalance at the best price level and the control variables measuring net trade volume from call and put options into equation (4).

$$\mu_{1,t} = \beta_0 + \beta_1 OF_{[t-1,t)} + \beta_2 F^*_{t-1} + \beta_3 OFC_{[t-1,t)} + \beta_4 OIC_{1,t-1}$$

$$+\beta_5 OFP_{[t-1,t)} + \beta_6 OIP_{1,t-1} + \varepsilon_{4,t} \qquad \dots\dots \qquad (5)$$

where $OFC_{[t-1,t)}$ and $OFP_{[t-1,t)}$ are the net trade volumes from Euro-Bund call and put options from minute t-1 to t. $OIC_{1,t-1}$ and $OIP_{1,t-1}$ are the book imbalances calculated by using equation (1) from order sizes at the best price levels in Euro-Bund futures call and put option order books at the minute of t-1. The reasons why we first limit our analysis of the book imbalance to the best level of prices in the Euro-Bund futures option order book are as follows. First, the quoting activities in the Euro-Bund futures option order book are irregular. We observe that there are not always 10 best price steps available across the option order book. Sometimes the order book only contains up to three price steps away from the best price level. They also tend to focus more on ATM and slightly OTM futures options. Second, in a less liquid market, quotes beyond the best price level may not contain meaningful information. Therefore, we investigate the quote imbalance at the best price level first. If we observe a significant result, then we add more quote size imbalance from additional price steps up to five best price steps.

In the above regression, we expect the sign of $OFC_{[t-1,t)}$ to be positive and the sign of $OFP_{[t-1,t)}$ to be negative, if options trading have impact on the future short-term Euro-Bund futures returns. When there are more buyer-initiated Euro-Bund futures call option trade contracts than seller-initiated call contracts (positive net trade volume) or more seller-initiated futures put option trade contracts than buyer-initiated put contracts (negative order flow), it may signal that investors expect the underlying futures value to move higher in the near future. Similarly, negative net trade volume from futures call options and positive net trade volume from futures put options may signal that investors expect the underlying futures price to move lower in the near future. Therefore, the positive sign of $OFC_{[t-1,t)}$ and negative sign of $OFP_{[t-1,t)}$ indicate that positive call option net trade volume and negative put option net trade volume signal favorable news on the fundamental value of futures while negative call option net trade volume and positive put option net trade volume signal unfavorable news on the fundamental value of futures. As a result, futures option trading could convey information about the underlying futures price movements.

We also expect the sign of $OIC_{1,t-1}$ to be negative and the sign of $OIP_{1,t-1}$to be positive. If there are more supply than demand sitting in futures call option order books, it may signal futures call prices to move lower. Because larger order sizes at the supply side will encourage more market sell orders of call options. These market sell call option orders will consume the limit order size sitting on the bid side of call option order books. As a result, the call prices expect to move downward. This may signal the underlying futures price tend to decrease because futures call prices are positively related to the underlying futures price.

However, if there are more demand than supply sitting in the futures put option order book, it may signal futures put prices to move upward because large order sizes at the demand size may drive more market buy orders of put options. These market buy put option orders will take the liquidity sitting on the ask side of the put option order book. As a result, the put option prices expect to move upward. This may convey information about a downward movement of the underlying futures price because the futures put price is negatively associated with the underlying futures price. Therefore, we expect futures call options book imbalance be negatively associated with future short-term futures returns and futures put options order imbalance to be positively related to future short-term futures return.

Under our research question, the null hypothesis in equation (5) is that the book imbalance at the best price level from the order book of the Euro-Bund futures option markets has significant impact on future short-term Euro-Bund futures returns after controlling for other factors. That is, $\beta_4 \neq 0 \; or \; \beta_6 \neq 0$. A rejection of the null hypothesis indicates that the order imbalance at the best price level in the futures option markets is not significantly related to futures price movements. If we can not reject the above null hypothesis, we further explore whether the order imbalances beyond the best price level in the futures option market contribute to future short-term futures price movement. The following regression will be run.

$$\mu_{1,t} = \beta_0 + \beta_1 OF_{[t-1,t)} + \beta_2 F^*_{t-1} + \beta_3 OFC_{[t-1,t)} + \beta_4 OIC_{1,t-1} + \beta_5 OFP_{[t-1,t)}$$

$$+\beta_6 OIP_{1,t-1} + \beta_7 FC_{n,t-1} + \beta_8 FP_{n,t-1} + \varepsilon_{5,t} \qquad \dots\dots \qquad (6)$$

where $FC_{n,t-1}$ is the common factor measuring the book imbalances from the second best step up to the best n steps in the futures call option market, and $FP_{n,t-1}$ is the common factor measuring the book imbalances from the second best step up to the best n steps in the futures put option market. The null hypothesis in equation (6) is that quote imbalances beyond the best price level from the order book of Euro-Bund futures options markets have significant impact on future short-term Euro-Bund futures returns after controlling for other factors. That is, $\beta_7 \neq 0\ or\ \beta_8 \neq 0$. A rejection of the null hypothesis indicates that quote imbalances beyond the best price level in the Euro-Bund futures option market are not significantly associated with Euro-Bund futures price movements.

5 Empirical Results

In this section empirical results are presented. First, we show how to use the principal component analysis to extract the common factor for book imbalances across price steps in the order book. Secondly, we present empirical evidences from the full sample and three subsamples with different levels of leverage measured by moneyness from Euro-Bund futures options. Then we explain our findings in the next subsection. The last section of this chapter discusses additional robustness tests on our findings. In all tables showing regression results, t statistics are shown below the coefficients of independent variables. And * and ** highlights that a coefficient is statistically significant at 5% and 10% levels.

5.1 A common factor of book imbalances

Before we perform the principal component analysis on order sizes across price steps of order book in order to identify a common factor measuring book imbalances across the order book, we first take log of cumulative order sizes and then use them as the inputs of the principal component analysis. We test our analysis of common factor for book imbalances across 2 to 10 steps of the order book in Euro-Bund futures markets. The one with the best explanatory power for short-term futures returns will be selected as the optimal one in our future analysis. In general, the second common factors extracted from the principal component analysis on logarithm of cumulative order sizes at different steps across the order book are qualitatively similar.

In order to save space, we only report the results of comparison from the first 5 and 10 price steps in the Euro-Bund futures order book. However, the conclusion holds qualitatively if we choose other price steps across the order book. Table 5 shows the cumulative explanatory power of the first five common factors from the principal component analysis. Panel A uses the first best five logs of cumulative order sizes on both the bid and asked sides to compute the common factors explaining the variation of quote sizes while Panel B uses all 10 logs of cumulative order sizes on both the bid and asked sides to compute the common factors. The cumulative explanatory power of the first three common factors in Panel A is 90.86%. The cumulative explanatory power of the first three and four common factors is 89.07% and 94.6%. Since we use 90% cumulative explanatory power as a cutoff of selecting common factors, we can easily identify the first three common factors (principal components) satisfying our criteria in both cases.

Table 5: First Five Common factors of Principal Component Analysis

Component	Eigenvalue	Difference	Proportion	Cumulative
Panel A : The First Five Best Steps				
F1	5.70542	2.89312	0.5705	0.5705
F2	2.8123	2.24416	0.2812	0.8518
F3	0.56814	0.01417	0.0568	0.9086
F4	0.55397	0.43154	0.0554	0.964
F5	0.12242	0.00416	0.0122	0.9762
Panel B: All Ten Best Steps				
F1	11.0764	5.65219	0.5538	0.5538
F2	5.42424	4.11103	0.2712	0.825
F3	1.31321	0.20788	0.0657	0.8907
F4	1.10532	0.77648	0.0553	0.946
F5	0.32883	0.03519	0.0164	0.9624

To test which common factor represents the book imbalances across steps of the order book, we run the model of (3) for each of the first three common factors, F1, F2, and F3 in each principal component analysis. The one with highest adjusted R^2 will be selected as the common factor representing book imbalances across steps of the order book because the adjusted R^2 indicates the power of independent variables on dependent variables after controlling for the number of independent variables. The results from these regressions are shown in Table 6.

Table 6: Time Series Regression of Common Factors on Order Imbalance						
	The First Five Best Steps			All Ten Best Steps		
	F1	F2	F3	F1	F2	F3
OI1	0.054	1.962	-0.316	0.073	1.702	-0.037
	2.160*	291.00*	-41.44*	2.09*	215.23*	-3.02*
OI2	-0.066	2.510	0.092	-0.216	2.599	0.039
	-1.450	207.22*	6.68*	-3.41*	182.55*	1.810
OI3	0.048	1.862	0.277	0.047	2.445	-0.008
	0.930	134.97*	17.71*	0.65	151.17*	-0.330
OI4	-0.120	1.194	0.211	0.011	2.139	-0.115
	-2.290*	85.07*	13.28*	0.14	127.13*	-4.47*
OI5	0.045	0.534	0.134	0.362	1.716	-0.034
	0.910	40.75*	9.01*	4.84*	102.03*	-1.320
OI6				-0.074	1.314	0.095
				-1.010	79.88*	3.78*
OI7				-0.227	0.913	0.100
				-2.98*	53.48*	3.80*
OI8				-0.239	0.651	0.121
				-3.00*	36.46*	4.44*
OI9				-0.298	0.414	0.058
				-3.99*	24.68*	2.25*
OI10				-0.411	0.172	-0.024
				-5.86*	10.920*	-1.000
Adj. R^2						
	0.001	0.85	0.05	0.003	0.90	0.002

When we use the first five steps in the order book, the adjusted R^2 for the first, second, and third common factors are 0.1%, 85%, and 5%. When we use all 10 steps of order book, the Adjusted R^2 for the first, second, and third common factors are 0.3%, 90%, and 0.2%. Clearly the second common factor, F2, has the most explanatory power for book differences across steps in the book. It represents scaled quote size imbalances between the supply and demand schedules. An interesting observance from Table 5 is that the coefficients of quote size imbalances at each price step are all positive and statistically significant at 5% level in both scenarios. Therefore, we can interpret the second common factor the same as scaled book imbalances, OIs, in the same economical way.

After identifying the second common factor as the common measure of quote imbalances across the order book, we next compare the explanatory powers of the second common factors from our experiments of using order sizes from 2 to 10 steps across the order book in order to select one for the analysis of our research questions. The literature has shown that the quote size difference between the bid and ask sides can predict short-term price changes (Huang and Stoll, 1994; Hollifield et al. 2004; Cao et al. 2009; among others). Based on these findings, we impose the following model to select the optimal steps, m, in the equation (4).

Table 7: Time Series Regression of Next Minute Euro-Bund Futures Return[5]

	(1)	(2)	(3)	(4)
Constant	0.000001	0.000001	0.000001	0.000001
	2.63*	2.64*	2.66*	2.66*
$OF_{[t-1,t)}$	0.000092	0.000092	0.000093	0.000093
	207.23*	211.66*	212.8*	211.45*
$F^*_{2,t-1}$		-0.00001		
		-37.1*		
$F^*_{5,t-1}$			-0.000007	
			-38.32*	
$F^*_{10,t-1}$				-0.000004
				-32.35*
Adj. R^2	0.496	0.511	0.519	0.509

Table 7 shows the results of comparisons of the second common factor extracted from the first best two and five, and all ten steps of the order book. $F^*_{2,t-1}$, $F^*_{5,t-1}$, and $F^*_{10,t-1}$ in these regressions are the second common factor representing scaled book imbalance between the supply and the demand schedules along the order book. In general, the results across three different measures for the book imbalances are qualitatively similar. All one-lagged second common factors from all three regressions are with the expected negative sign and statistically

[5] The Breusch–Godfrey serial autocorrelation LM Tests show that there are no autocorrelations for residuals of each regression model in Table 7. We also conduct the similar autocorrelation tests for all regression models in the rest of the dissertation. The results show that there is no autocorrelation in the residuals.

significant at 5% level. This is in line with the theory that more supply than demand in the Euro-Bund futures order book will encourage traders to use more market sell order. As a result, it will take liquidity on the bid side of the book, driving down Euro-Bund futures price. In terms of the Adjusted R^2, the second common factor extracted from the first 5 steps of the order book has a little better explanatory power on future Euro-Bund futures returns with a value of 51.9%. And in terms of Akaike information criterion (AIC) from these models, regression (3) in Table 7 has the minimum value. Therefore, we decide to use the second common factor extracted from the first five steps of the order book in Euro-Bund futures markets as a measure of the book imbalance as an input for the analysis of our research question.

5.2 Book imbalances and short-term return

After the design for one common factor representing quantity imbalance between demand and supply schedule in the order book, we can explore our main research question on whether book imbalances across Euro-Bund futures options markets are related to short-term Euro-Bund futures price movements.

Table 8 presents the results of regression model (5) from four different sample data, the full sample containing all valid options, OTM, ATM, and ITM options samples. The main variables of interest in this model are $OIC_{1,t-1}$ and $OIP_{1,t-1}$. In order to directly investigate our research question, we perform a joint F test with the null hypothesis that the coefficients of $OIC_{1,t-1}$ and $OIP_{1,t-1}$ are both equal to zero, that is $\beta_4 = \beta_6 = 0$ in model (5). If the coefficients of $OIC_{1,t-1}$ and $OIP_{1,t-1}$ are with expected sign and statistically significant, we can claim that the book imbalance at the best bid and ask limit price level in Euro-Bund futures option markets has significant impact on Euro-Bund futures returns. Therefore, we support our research hypothesis claimed in the literature review section. Although the estimated coefficients of $OIC_{1,t-1}$ and $OIP_{1,t-1}$ have the expected sign in the full sample regression, the p-value of F statistic for the joint test that is 0.55, greater than 5% significant level. Therefore we fail to reject the null hypothesis of the joint F test. In other words, after controlling for trades in Euro-Bund futures and futures option markets and the book imbalance in Euro-Bund futures markets, there is no evidence that the book imbalance on the best bid and ask sizes of the futures option order book can be used to predict next minute futures returns in the full sample.

Table 8: Time Series Regression of Minute Euro-Bund Futures Return Using Options Data

	All	OTM	ATM	ITM
Constant	0.000002	0.000000	0.000002	0.000003
	0.95	0.28	0.076	1.07
$OF_{[t-1,t)}$	0.000092	0.000096	0.000092	0.0000808
	65.09*	86.78*	113.87*	35.85*
$F^*_{5,t-1}$	-0.000013	-0.000011	-0.0000104	-0.000014
	-12.25*	-15.18*	-21.07*	-8.64*
$OFC_{[t-1,t)}$	0.000004	0.000004	0.000003	0.000021
	4.02*	3.99*	4.91*	4.28*
$OFP_{[t-1,t)}$	-0.000007	-0.000005	-0.000005	-0.000006
	-6.45*	-4.17*	-7.31*	-3.87*
OIC_{t-1}	-0.00001	-0.000001	-0.000002	-0.000008
	-1.59	-0.22	-1.1	-0.69
OIP_{t-1}	0.000005	0.000001	0.000005	0.0000131
	0.73	0.17	2.21*	1.33
p-value of F Stat.	0.550	0.958	0.041	0.34
Adj. R^2	0.641	0.604	0.597	0.659

However, the full sample does not distinguish the different levels of leverage provided by options with varying moneyness. Easley et al. (1998) show that the levels of leverage from options play an important role in determining the place to trade for informed traders (smart traders in this dissertation). In other words, traders will not just choose to trade or place orders for futures, futures call or put options, but rather choose between futures and futures options with differing levels of leverage. The regression results from equation (5) by using OTM, ATM, and ITM futures options are shown in the last three columns of Table 7. The p-values of F statistic from the joint test in OTM and ITM regressions are 0.958 and 0.34. Both are greater than 5% significant level. We fail to reject the null hypothesis of the joint F test that the coefficients of $OIC_{1,t-1}$ and $OIP_{1,t-1}$ are both equal to zero in both OTM and ITM regressions. However, the p-value of F statistic for the joint test in ATM regressions is 0.041, less than 5% significant level. Therefore, after controlling trades and quotes in Euro-Bund futures markets and trades in its options markets, the order book imbalance between the supply and the demand at the best price level of the ATM Euro-Bund futures option order book is statistically significantly associated with future returns of Euro-Bund futures.

The signs of estimated coefficients of $OIC_{1,t-1}$ and $OIP_{1,t-1}$are expected. The negative sign of $OIC_{1,t-1}$indicates there is an inverse relation between book imbalance in futures option markets and futures prices. The higher $OIC_{1,t-1}$ represents more supply than demand placing in futures call option order book. This sends an unfavorable signal to traders by implying futures call prices to move downward because larger order sizes at the ask side may trigger more market sell orders of futures call options. These market sell futures call option orders will take the liquidity offered on the bid side of futures call option order book. As a result, futures call prices tend to move lower. This may imply the underlying futures price will move lower because futures call prices is positively related to the underlying futures price, other things held constant. In this case, the more supply relative to the demand on Euro-Bund futures options is an unfavorable signal for call options, but is a favorable signal for the underlying futures price.

The positive sign of $OIP_{1,t-1}$also confirms our expectation. The higher $OIP_{1,t-1}$indicates more supply than demand sitting in the Euro-Bund futures put option order book. Similarly, the more supply of futures put options relative to its demand is an unfavorable signal for futures put prices. However, it is a favorable signal for the underlying futures price because futures put prices are negatively related to the underlying futures price, other things held constant.

The t statistic of the estimated coefficient on $OIC_{1,t-1}$is not statistically significant at 5% significant level, while the t statistic of estimated coefficient on $OIP_{1,t-1}$ is statistically significant at 5% level. This provides evidence that the signal extracting from book imbalance regarding the supply and demand schedule in Euro-Bund futures ATM put option markets dominates that from its ATM call option markets. This is also confirmed by magnitudes of $OIP_{1,t-1}$ and $OIC_{1,t-1}$. The estimated coefficient of the book imbalance in futures ATM put options is relatively larger than that on futures call options.

All estimated coefficients of controlled variables are statistically significant at 5% level, and their signs are in line with theoretical expectations in the discussion of methodology. More buyer-initiated than seller-initiated Euro-Bund futures trade contacts send a favorable signal on futures prices leading to an upward revision of futures price. More supply than demand sitting on bid and ask sides of the Euro-Bund futures order book encourages market sell orders, driving futures price lower. More buyer-initiated than seller-initialed futures call option trade volume also sends a favorable signal about upward movement of futures price. However, more buyer-initiated than buyer-initiated futures put option transaction volume sends an unfavorable signal on futures prices, driving futures prices lower.

After identifying a significant association between book imbalances at the best price level across Euro-Bund futures ATM option order book and its futures price movement, we proceed to examine whether book imbalances beyond the best price levels are also significantly related to futures price movement by running the regression model (6). The additional common factors measuring incremental book imbalance at selected additional price steps across both sides of the order book are extracted from the principal component analysis.

When we examine the depth of Euro-Bund futures ATM option order book, we find that not all 10 steps are filled by traders, and the depth changes over time. Therefore, we limit our analysis to the best five price steps on both bid and asked sides of the Euro-Bund futures option order book in order to have enough paired observations to perform the principal component analysis. Table 9 reports the results of these regressions. In general, inclusion of incremental book imbalances from additional following two or four best price steps in Euro-Bund futures option order book does not provide any explanatory power on the underlying futures price movement, since the estimated statistics of these additional common factor measures in both column (2) and (3) are not statistically significant and Adjusted R^2 has not been improved. Therefore, only the book imbalance between the supply and the demand on the best bid and asked sides in the Euro-Bund futures option markets can explain the Euro-Bund futures price movement.

This finding may be first due to relative quote sizes at the best price levels in the Euro-Bund futures ATM option order book. The average quote sizes of the best and ask sizes per minute are 2,535 contracts per minute for the futures ATM put option and 2,759 contracts for its call option. If we compare this with the average trade sizes per minute in Table 2, this may be part of explanations on that. Secondly, the trading cost in Euro-Bund futures option market is relatively high when traders walk through the Euro-Bund futures option order book from the best price levels because the bid-ask spread in the Euro-Bund futures market almost always maintain at one tick. Therefore, moving back to a step inferior than the best price levels would at least double the trading costs in Euro-Bund futures option markets relative to trades in its underlying futures markets. This will deter traders to take liquidity sitting on steps beyond the best limit price. Therefore, quote sizes beyond the best level in the Euro-Bund futures option order book contain little information on Euro-Bund futures movements.

Table 9: Time Series Regression of Minute Euro-Bund Futures Return Using Quotes Imbalances Beyond the Best Price Level

	(1)	(2)	(3)
Constant	0.000002	0.000002	0.000002
	0.76	0.81	0.79
$OF_{[t-1,t)}$	0.000092	0.0000918	0.000092
	113.87*	113.88*	113.88*
$F^*_{5,t-1}$	-0.0000104	-0.0000103	-0.000010
	-21.07*	-20.97*	-21.04*
$OFC_{[t-1,t)}$	0.000003	0.000003	0.000003
	4.91*	4.9*	4.89*
$OFP_{[t-1,t)}$	-0.000005	-0.000005	-0.000005
	-7.31*	-7.31*	-7.29*
OIC_{t-1}	-0.0000022	-0.0000022	-0.0000021
	-1.1	-0.69	-0.71
OIP_{t-1}	0.0000045	0.0000050	0.0000051
	2.21*	2.48*	2.02*
$FC_{2,t-1}$		-0.00000005	
		-0.03	
$FP_{2,t-1}$		0.000003	
		1.42	
$FC_{4,t-1}$			-0.000001
			0.415
$FP_{4,t-1}$			0.000001
			0.707
Adj. R^2	0.597	0.597	0.596

5.3 Discussion of findings

The result that only the book imbalance at the best limit price levels in the Euro-Bund futures ATM option markets is significantly associated with its futures markets return is different with the majority of recent empirical evidence that traders prefer using OTM options when they have information advantage than others in equity markets (Cao et al., 2005; Pan and Poteshman, 2006; among others). Now, the interesting question is why Euro-Bund futures ATM put options are relatively more informative to its futures price movements in our sample.

There are several reasons. First, trading in Euro-Bund futures markets is normally leveraged by its margin requirement. However, margined futures-style premium in Euro-Bund futures options markets offset the leverage effect embedded in Euro-Bund futures contract. Therefore, the choice of which exercise price for transactions or for placement of orders depends on the relative trading cost in Euro-Bund futures markets to that in its futures option markets, and the leverage provided by these options.

Table 10: Average bid-ask spread for Euro-Bund Futures Options

	OTM	ATM	ITM
CALL	0.063	0.020	0.013
PUT	0.068	0.023	0.013

Table 10 reports the average bid-ask spread for Euro-Bund Futures Options with different levels of leverage. The results are almost consistent with those in the equity option markets except Euro-Bund futures ITM options. Futures OTM options with the highest leverage have the largest average bid-ask spread 0.063 for futures calls and 0.068 for futures puts, followed by its

ATM options with average values of 0.02 for futures calls and 0.023for futures puts. However, Euro-Bund ITM options with an average bid-ask spread of 0.013 for futures calls and puts.

Low trading activity for Euro-Bund futures ITM options in Table 4 confirms that futures ITM options are not favored by traders. The possible reason is because of its relatively high trading cost to its underlying Euro-Bund futures and low leverage[6]. The trading cost for Euro-Bund futures OTM options is very high relative to the mean daily high-minus-low Euro-Bund futures price change, 0.40 in the sample. This high trading cost will offset the benefit of high leverage provided by futures OTM options. Therefore, we did not observe large trading volume for Euro-Bund futures OTM options.

As predicted by the theory, the choice to trade or to place orders in the Euro-Bund futures ATM option markets depends on relative trading cost, measured by the average bid-ask spread, in Euro-Bund futures to that in its futures option markets and the level of leverage from these ATM options. As shown in Table 4 Euro-Bund futures ATM options have dominantly high trading volume. However, these options have much lower bid-ask spread than OTM options, but a little bit higher than ITM options. This is consistent with the tradeoff between leverage and relative trading costs in the Euro-Bund futures and futures option markets. The result is very similar to that in Kaul et al. (2002), who show that the ATM and slightly OTM option spreads are the most sensitive to asymmetric information measures in the stock.

To justify this theoretical projection, we divide the Euro-Bund futures ATM option sample into two subsamples. One is data with average bid-ask spread below two ticks, which is a little below the mean value of these ATM options. The other is data with above three ticks, which denotes periods during which trading cost is relative high. If the theoretical projection is

[6] de Jong et al. (2001) argue that corporate insiders may favor ITM options since the tendency to trade for them is high once options are deep in the money. In their model, insiders are assumed to have material information, which is quite different from our definition of smart investors. Therefore, their setting does not apply here.

correct, then we expect results from the sample with average bid-ask spread below two ticks to hold qualitatively the same as those for Euro-Bund futures ATM options in Table 7, while the results from sample with average bid-ask spread above three ticks are statistically different.

We re-examine the time series regression of model (5). Results are reported in Table 11. Column (1) in the table shows the results for the sample below two ticks. The results we find in the table hold qualitatively. In this specification the book imbalance at the best price levels of Euro-Bund futures option markets is jointly significantly related to its futures price movements (p_value of joint test is 0.047), and put option book imbalance dominates (coefficient 0.000044, t-statistic of 2.17) call option book imbalance (coefficient -0.000023, t-statistic of -1.17). Control variables have the same sign as results in Table (5).

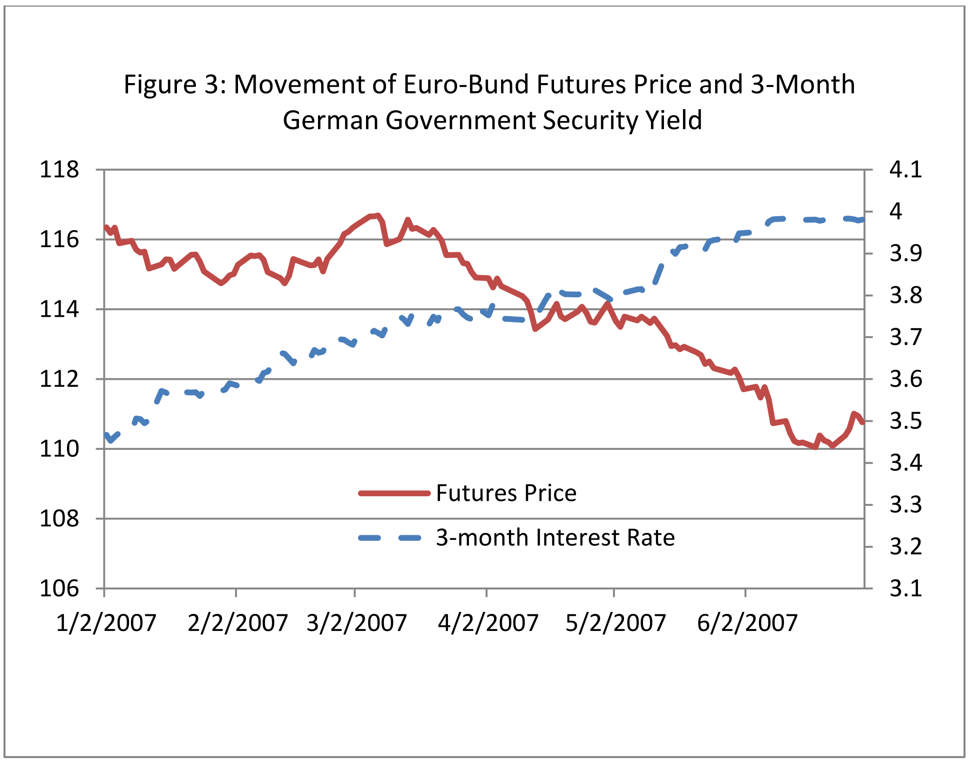
Table 11: Time Series Regression Using ATM Options Data with Different Trading Costs

	(1)	(2)
Constant	0.0000010	0.0000084
	1.15	2.15*
$OF_{[t-1,t)}$	0.000086	0.0001149
	105.51*	39.7*
$F^{*}_{5,t-1}$	-0.000009	-0.0000193
	-18.71*	-8.18*
$OFC_{[t-1,t)}$	0.0000035	-0.0000003
	5.39*	-0.11
$OFP_{[t-1,t)}$	-0.0000045	-0.000004
	-6.94*	-1.28
OIC_{t-1}	-0.0000023	-0.0000115
	-1.17	-1.18
OIP_{t-1}	0.0000044	0.0000087
	2.17*	0.87
p-value of F Stat.	0.047	0.349
Adj. R^2	0.606	0.618

More interestingly, results for the sample above three ticks in column (2) justify our theoretical projection that relative trading costs between Euro-Bund futures and futures option markets and the leverage from ATM futures options determine where traders choose to place orders in the option market. The estimated coefficient of $OIP_{t-1}$is not statistically significant at 5% level any more. And the p_value for the joint test on the book imbalance between the supply and demand schedules across the Euro-Bund futures option order book is 0.349, which is much larger than 5% confidence level. Therefore, we can claim that the book imbalance between the supply and demand schedules across the Euro-Bund futures option order book is not statistically significantly related to Euro-Bund futures price movements. Moreover, the t-statistics of order flow in both Euro-Bund futures call and put options are not statistically significant at 5% level. Comparing with those in Table 7, the estimated coefficient of futures call option has wrong sign, but much smaller magnitude, while its put option has expected sign and similar magnitude.

The statistical results in regressions (1) first clearly indicate that when the trading cost is low enough to take leverage benefits from Euro-Bund futures ATM options, smart traders are willing to use market orders to exploit their advantage. The statistical significance of the order book imbalance may be explained as follows. 1) If the value of their advantage in this case is less than the bid-ask spread in Euro-Bund futures ATM option markets, some smart investors are willing to wait by placing limit orders at the best price levels of its futures ATM options. And 2) if market makers who have transactions with smart investors infer that the probability for the underlying futures price to change becomes larger, they will adjust their quotes by reducing or adding quote size at the best limit prices of the book. However, our data cannot help us tell which interpretation is more likely since we don't have information to identify whether an order is from market markers.

Other variables from Euro-Bund futures markets are statistically significant at 5% level and have the expected sign as predicted by the theory. Therefore, when the bid-ask spread is relative higher than the leverage benefit from Euro-Bund futures ATM options, smart traders with better knowledge about future movement of interest rate choose not to trade and place orders in the Euro-Bund futures ATM option market. When the bid-ask spread is relatively low, information in the Euro-Bund futures ATM option order book is significantly associated with the Euro-Bund futures market. The findings strongly support the notion that market choice of trades mainly depends on the relative trading cost in Euro-Bund futures to that in its futures option markets as well as the leverage offered by these two markets.



Secondly, the choice of Euro-Bund futures put option also depends on market conditions. When the market expects to be in the downturn (futures price goes down and interest rate goes up) during this period, then trading futures put options are more likely than trading futures call options because buying futures puts is less risky than writing futures calls. In Figure 3, we plot the movements of the front month Euro-Bund futures daily price and three-month German government security yield from January 2, 2007, to June 29, 2007. Obviously there are downside risks of Euro-Bund futures in this specific period due to upward movement of interest rates from the Euro zone and the U.S. in the first half year of 2007. This market environment may determine the importance of Euro-Bund futures ATM put options more than its ATM call option because puts can be used for protection against interest rate risks.

Table 12: Time Series Regression Using ATM Options Data with Different Periods

	Before 03/10/2007	After 03/10/2007
Constant	0.0000010	0.0000087
	0.79	1.51
$OF_{[t-1,t)}$	0.0000902	0.0000963
	84.82*	88.97*
$F^*_{5,t-1}$	-0.0000105	-0.0000103
	-15.95*	-14.84*
$OFC_{[t-1,t)}$	0.0000035	0.0000029
	4*	3.37*
$OFP_{[t-1,t)}$	-0.0000028	-0.0000063
	-3.09*	-7.22*
OIC_{t-1}	-0.0000032	-0.0000014
	-1.17	-0.75
OIP_{t-1}	0.0000021	0.0000068
	0.74	2.55*
p-value of F stat.	0.381	0.032
Adj. R^2	0.605	0.621

To test this explanation, we divide the Euro-Bund futures ATM option sample into two subsamples. One is data before 03/10/2007. The other is data after that date. The cutoff is the date in which we believe the downturn starts. Table 12 reports our results of regression (5) by using these two subsamples. The estimated coefficient of $OIP_{t-1}$is statistically significant at 5% in the data sample after 03/10/2007, but not in the sample before 03/10/2007. The magnitude is also larger in the data sample after 03/10/2007. The magnitude of the estimated coefficient of $OFP_{[t-1,t)}$ is larger while the magnitude of the estimated coefficient of OIC_{t-1} becomes smaller in the data sample after 03/10/2007. In our sample, seller-initiated futures ATM puts are traded 37.59% more than seller-initiated calls in the sample after 03/10/2007 while there are only 4.92 percent more in the sample before 03/10/2007. Therefore, there is clear evidence showing that during a period with negative news surprises, Euro-Bund futures ATM put option plays an important role in price formation of Euro-Bund futures.

To assess economic meaning of our findings in Table 7, let's look at a specific example from our sample. At 14:42:00 CET on January 5, 2007, Euro-Bund futures mid-quote price was 115.975. Under our definition of ATM, Euro-Bund ATM futures options are options with exercise prices of 115.5 and 115.60. The best bid and ask sizes pairs of two Euro-Bund ATM put options were (1482, 1239) and (1860, 776) at 14:42:00 CET. The OI1 = (1239 +776 – 1482 – 1860) / (1239 +776 + 1482 + 1860) = -0.075. The negative OI1 of Euro-Bund futures ATM options at 14:42:00 predicts that the underlying Euro-Bund futures price tends to drop from 14:42:00 CET to 14:43:00 CET. The Euro-Bund futures mid-quote price dropped from 115.975 at 14:42:00 CET to 115.905 at 14:43:00 CET. Based on this prediction, if we short one contract of Euro-Bund futures at 14:42:00 CET. The tick return from this transaction is 7 ticks, which corresponds to EUR 70. This profit is large enough to cover the bid-ask spread and commission fee charged by the exchange. Therefore, our result has economic meaning.

5.4 Other robustness tests

In order to check for the robustness of our empirical results, we also employ several variations of equation (5). First we replace the book imbalance common factor, $F^{*}_{j,t-1}$, by book imbalances measured in equation (2) at the best m price levels in the Euro-Bund futures order book. The regression model is as follows.

$$\mu_{1,t} = \beta_0 + \beta_1 OF_{[t-1,t)} + \sum_{i=1}^{m} \beta_{2,i} OI_{i,t-1} + \beta_3 OFC_{[t-1,t)} + \beta_4 OIC_{1,t-1}$$

$$+\beta_5 OFP_{[t-1,t)} + \beta_6 OIP_{1,t-1} + \varepsilon_{5,t} \qquad \dots\dots \qquad (7)$$

Table 13 reports the regression results by using the full, OTM, ATM, and ITM samples. Results are qualitatively similar to our findings. Again in this specification with Euro-Bund futures option markets are statistically significantly related to futures price movements (p_value of joint test is 0.047). And puts option book imbalance dominates (coefficient 0.000005, t-statistic of 2.25) calls option book imbalance (coefficient -0.000002, t-statistic of -0.88).

Secondly, we measure the book imbalance by looking at price impact of a given trade volume, Q, on both bid and asked sizes of the order book. The price impact is deemed as an ex ante cost of trading for a hypothetical given trade volume. Specifically, the market price impact on bid or ask side is measured as the price difference between volume weighted average price paid for the given trade quantity and the mid quote price at a given timestamp. Let $PIA_t(Q)$ be the price impact measure of Q futures contract on the ask side of order book at the minute t. Mathematically it is calculated as the following.

$$PIA_t(Q) = \frac{\sum_{i=1}^{n-1} P_i^A S_i^A + P_n^A Q_n^*}{Q} - \frac{P_1^A + P_1^B}{2} \quad \dots\dots\dots. \ (7)$$

$$Q = \sum_{i=1}^{n-1} S_i^A + Q_n^*$$

$$and \sum_{i=1}^{n-1} S_i^A < Q \leq \sum_{i=1}^{n} S_i^A$$

where P_1^A and P_1^B are the best asked and bid prices in the order book. P_i^A and S_i^A are the limit price and asked size for step i on the asked side of order book. In this case the specific market

Table 13: Time Series Regression of Minute Euro-Bund Futures Return After Controlling for Scaled Quote Imbalances

	Full	OTM	ATM	ITM
Constant	0.000003	0.000001	0.000002	0.000004
	1.27	0.83*	2.72*	1.54
$OF_{[t-1,t)}$	0.000091	0.000095	0.000091	0.0000787
	64.17*	85.84*	113.31*	35.32*
$OI1_{t-1}$	-0.0000273	-0.000032	-0.000029	-0.0000231
	-5.42*	-10.65*	-13.26*	-3.17*
$OI2_{t-1}$	-0.0000599	-0.000035	-0.000047	-0.0000518
	-7.38*	-7.08*	-13.09*	-3.94*
$OI3_{t-1}$	-0.0000376	-0.0000282	-0.0000273	-0.0000152
	-3.72*	-4.58*	-6.11*	-1.04
$OI4_{t-1}$	-0.0000156	-0.0000146	-0.000003	-0.0000241
	-1.52	-2.28*	-0.57	-1.53
$OI5_{t-1}$	-0.000005	-0.000001	-0.000001	-0.000007
	-0.48	-0.18	-0.32	-0.18
$OFC_{[t-1,t)}$	0.000004	0.000003	0.000003	0.000021
	3.79*	3.79*	4.77*	4.22*
$OFP_{[t-1,t)}$	-0.000007	-0.000005	-0.000005	-0.000007
	-6.38*	-3.96*	-7.44*	-4.11*
OIC_{t-1}	-0.0000112	-0.000002	-0.000002	-0.000006
	-1.61	-0.44	-0.88	-0.52
OIP_{t-1}	0.000004	0.0000001	0.000005	0.0000111
	1.27	0.02	2.25*	1.11
p value	0.648	0.590	0.047	0.409
Adj. R^2	0.637	0.603	0.598	0.652

order will sweep the first n-1 steps at the asked side of the order book and fulfill the rest of Q_n^* in order to reach the order of Q contracts of Euro-Bund futures. The price impact measure on the asked side is just the premium per share that a market-order buyer pays above the midpoint of the best and asked prices for trading Q futures contract at the minute t.

We can define the price impact measure on the bid side of order book, $PIB_t(Q)$, in a similar way. It is calculated as the following.

$$PIB_t(Q) = \frac{P_1^A + P_1^B}{2} - \frac{\sum_{i=1}^{n-1} P_i^B S_i^B + P_n^B Q_n^*}{Q} \quad \dots\dots\dots \ (8)$$

$$Q = \sum_{i=1}^{n-1} S_i^B + Q_n^*$$

$$and \ \sum_{i=1}^{n-1} S_i^B < Q \leq \sum_{i=1}^{n} S_i^B$$

Intuitively, the price impact measure on the bid side of order book is just the discount per share that a market-order seller receives below the mid quote price at the minute t. If the absolute value of PIB is very large, it means investors using market sell order to trade Q contracts of Euro-Bund futures will receive higher discount on the actual price he would get. In other words, the trading cost of using market sell order would be really high when the discount is large.

Therefore, PIB(Q) and PIA(Q) are inversely related to liquidity in the order book. Basically, PIB(Q) (PIA(Q)) measures the illiquidity at the bid (ask) side of order book. Next, we follow Cao et al. (2009) to compute the scaled imbalance in price impact for a given trade volume, Q. It is defined as the following.

$$PI_t(Q) = \frac{PIA_t(Q) - PIB_t(Q)}{PIA_t(Q) + PIB_t(Q)} \quad \dots\dots \ (9)$$

In this dissertation, we look at two different levels of trade volume in the Euro-Bund futures market. One is the normal case, which is the average trade volume of Euro-Bund futures, 2,083 contracts, in one-minute interval. The other is an extreme case, which we denote as five times of mean minute-level trade volume in futures markets, 10,415. We use these two PI values to modify equation (5)

$$\mu_{1,t} = \beta_0 + \beta_1 OF_{[t-1,t)} + \sum_{i=1}^{2} \beta_{2,i} PI_{i,t-1} + \beta_3 OFC_{[t-1,t)} + \beta_4 OIC_{1,t-1}$$

$$+\beta_5 OFP_{[t-1,t)} + \beta_6 OIP_{1,t-1} + \varepsilon_{6,t} \quad \dots\dots \ (10)$$

where $PI_{1,t}$ denotes the normal case, while $PI_{2,t}$represents the extreme case. We expect to see positive relation between scaled book imbalance in price impact and next minute return in Euro-Bund futures markets. If $PI_{i,t}$ is negative, we see a larger price impact on the demand side than on the supply side. It implies that there are more limit sell orders sitting at sell price steps than limit buy orders placed at buy price steps. As a result it will attract more market sell orders, and drive the futures price lower.

Table 14 reports the regression results by using the full, OTM, ATM, and ITM option samples. Results are qualitatively similar to our findings in Table 7. The sign of PIs have expected negative sign and are both statistically significant in most regressions. Again, only the book imbalance at the best price levels of Euro-Bund futures ATM option markets is statistically significantly related to futures price movements (p_value of joint test is 0.037). And puts quote imbalance dominates (coefficient 0.000004, t-statistic of 2.25) call quote imbalance (coefficient -0.000003, t-statistic of -0.88). Other coefficients are similar as well.

We find that our results qualitatively hold if we use five-minute sampling data to run regression model (5) in Table 15. The book imbalance at the best price level of Euro-Bund futures ATM put options markets are statistically significantly related to futures price movements (coefficient 0.0000028, t-statistic of 1.81) at 10% significant level. Other coefficients are similar as well.

Table 14: Time Series Regression of Minute Euro-Bund Futures Return After Controlling for Price Impact

	ALL		OTM		ATM		ITM	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Constant	0.000001	0.000003	0.000001	0.000002	0.000001	0.000002	0.000001	0.000004
	3.79*	1.25	3.33*	1.35	3.72*	2.42*	3.54*	1.31
OF (t-1, t)	0.000092	0.000090	0.000093	0.000094	0.000092	0.000090	0.000088	0.000078
	211.55*	63.54*	201.83*	85.21*	211.16*	111.72*	206.43*	34.38*
PI1(t-1)	0.000037	0.000013	0.000036	0.000028	0.000037	0.000028	0.000036	-0.000025
	20.99*	1.1	19.68*	4.01*	20.99*	5.57*	21.44*	-1.57
PI2(t-1)	0.000040	0.000134	0.000040	0.000087	0.000040	0.000086	0.000039	0.000176
	15.5*	8.14*	14.63*	8.5*	15.5*	11.93*	15.62*	7.65*
OFC (t-1, t)		0.000004		0.000003		0.000003		0.000021
		3.64*		3.56*		4.62*		4.17*
OFP(t-1,t)		-0.000007		-0.000004		-0.000005		-0.000007
		-6.31*		-3.77*		-7.17*		-4.13*
OIC (t-1)		-0.000013		-0.000003		-0.000003		-0.000005
		-1.76		-0.77		-1.26		-0.46
OIP(t-1)		0.000001		-0.000001		0.000004		0.000011
		0.2		-0.26		2.37*		1.11
p_value		0.247		0.811		0.037		0.323
Adj. R^2	0.514	0.632	0.514	0.600	0.514	0.596	0.508	0.641

Table 15: Time Series Regression of Five-Minute Euro-Bund Futures Return With Options Data

	ALL		OTM		ATM		ITM	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Constant	0.000002	0.000003	0.000002	0.000002	0.000002	0.000003	0.000002	0.000002
	2.03*	0.25	1.71	1.52	2.03*	1.89**	2.42*	2.42*
OF_F (t-1, t)	0.000023	0.000021	0.000023	0.000022	0.000023	0.000022	0.000021	0.000021
	40.01*	34.76*	38.34*	34.1*	40.01*	37.6*	39.57*	38.36*
CF2_F(t-1)	-0.000002	-0.000002	-0.000002	-0.000002	-0.000002	-0.000002	-0.000002	-0.000002
	-2.85*	-3.00*	-2.60*	-2.27*	-2.85*	-2.91*	-2.79*	-2.78*
OFC (t-1, t)		0.000003		0.000004		0.000001		0.000029
		5.05*		4.9*		1.69		6.19*
OFP(t-1,t)		-0.000004		-0.000004		-0.000004		-0.000001
		-6.56*		-3.8*		-5.99*		-0.95
OIC (t-1)		0.0000028		-0.0000003		-0.0000001		0.0000050
		0.7		-0.1		-0.04		1.22
OIP(t-1)		0.0000035		0.0000004		0.0000028		0.0000033
		0.82		0.11		1.81**		0.76
Adj. R^2	0.153	0.165	0.152	0.163	0.153	0.161	0.151	0.158

6. Conclusions

Most empirical literature regarding price discovery between the underlying security and its derivatives markets focuses on trading volume related measures, such as net trade volume and put-call ratio in equity markets. Very few of them explore the possibility that the information content of the option order book may play an important role in determining the underlying security price. This dissertation uses one-minute sampling data on Euro-Bund futures and futures options extracted from the Eurex Historical order book to take a further step to examine the information content of book imbalances in the Euro-Bund futures option order book for its futures price movements.

We employ the principal component analysis to extract a common factor measuring book imbalances across the order book, and use it as a variable to investigate our research question. In time-series regressions we first find that only the book imbalance at the best bid and asked price levels in Euro-Bund futures ATM option markets is significantly related to short-term Euro-Bund futures returns. Our further investigation by including information from additional price steps in the Euro-Bund futures ATM option order book shows that the book imbalance beyond the best price levels is not informative to the price formation in the Euro-Bund futures market. We find that this is due to low trading volume and large quote size in the Euro-Bund futures ATM option market.

We also explore the tradeoff between leverage and relative trading cost in Euro-Bund futures market to tat in its futures ATM option markets. We show that Euro-Bund futures ATM options dominate other options in terms of trading volume while it has relatively low bid-ask spread. Our regression analysis shows that, when trading cost is relatively high, there is no price discovery from the Euro-Bund futures ATM option markets to its futures market. When the trading cost is relatively low, information in Euro-Bund futures ATM option markets is significantly associated with its futures price movements.

We finally show that the dominance of Euro-Bund futures ATM put options is mainly driven by market conditions. We find that in a period with more interest rate risks trading Euro-Bund futures ATM put options are more popular than its futures ATM call options. The regression results show that the futures ATM put options are more informative than its ATM call options for the underlying futures price formation in the period with high interest rate risks. Our results are specific to our sample period; therefore, extrapolation of our results to other periods would only be conjectural since market environment changes over time.

A limitation of our research is that we don't have data on traders' identities and all trades in OTC Euro-Bund futures option markets. As a result, we can not explicitly test our explanations on the impact of order imbalance in Euro-Bund futures options markets on price movements in Euro-Bund futures. Careful modeling the trade-off between market order and limit orders in Euro-Bund futures option markets could yield new insights about the economics of trading and submission strategies, and tradeoff between leverages and trading costs of options with different moneyness in futures options markets.

The limitations also bring future research guidance. If data are available, we can further explore our analysis. One of futures research is looking at similar markets, such as Euro-Boble and Euro-Schatz futures options markets, to study whether our results hold. Another futures research is looking at building trading strategies which could yield profitable results by using data with higher frequency.

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