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ABSTRACT

This work uses financial markets connected by arbitrage relations to investigate the dynamics of price and liquidity discovery, which refer to the cross-instrument forecasting power for prices and liquidity, respectively. Specifically, we seek to understand the linkage between the cheapest to deliver bond and closest futures pairs by using high-frequency data on European governments obligations and derivatives. We split the 2019-2021 sample into three subperiods to appreciate changes in the liquidity discovery induced by the COVID-19 pandemic. Within a cointegration model, we find that price discovery occurs on the futures market, and document strong empirical support for liquidity spillovers both from the futures to the cash market as well as from the cash to the futures market.

JEL classification: G12, G13, G15
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1 Introduction

The market liquidity of financial assets has deservedly received increasing attention in recent years among academics, practitioners and regulators. It is now well understood that liquidity and liquidity risk are reflected in the prices of financial assets and should be taken into account by investors in their asset allocation decisions. The importance of this issue is reflected in the vast academic literature on this topic covering many classes of assets, stocks, bonds, and derivatives in a variety of countries. Similarly, most practitioners are increasingly employing formal or informal models to incorporate liquidity into their asset allocation decisions. Liquidity is also a central concern of regulators, who now require financial institutions to maintain capital to address the potential illiquidity of their asset portfolios.

Liquidity discovery refers to the transmission of liquidity between assets linked to each other through arbitrage. In the context of liquidity discovery, for example in the case of spot and futures markets, the transmission of liquidity shocks is likely to be even stronger. This paper aims to investigate the microstructure of the relationship between liquidity discovery, through changes in the quotes posted by market makers and the reactions of arbitrageurs, and price discovery, the transmission of price shocks between markets. Indeed, by impounding news about prices in quotes market participants simultaneously reveal innovations in liquidity (see, e.g., O'Hara, 2003).

Our empirical analysis covers the French, German, and Italian sovereign bond cash and futures markets, over the last three years, including the time of the COVID-19 pandemic. It is based on tick-by-tick data provided by the Mercato dei Titoli di Stato (MTS), for the cash bonds, and Refinitiv, for the futures contracts. We study how the liquidity in the two markets is linked and how their relationship changed during the period of stress following the outbreak of the pandemic.[1]

The investigation of the commonality of liquidity and liquidity discovery is particularly relevant given the progressively stronger linkages across markets, due to faster access to information and trade execution, and the degree to which, and speed with which, liquidity is transmitted across markets today. An aspect of this issue is the extent to which a liquidity shock in one market

[1] Largely in line with the analysis already developed during the European Sovereign financial crisis in Pelizzon et al. (2014)

is transmitted ("spills over") into another. We find that the transmission mechanism studied by analysing the linkages between futures-cheapest to delivery pairs is informative over and above market-wide liquidity factors.

The importance of liquidity discovery across assets linked by arbitrage is heightened by the fact that liquidity is provided not only by market makers, but also by arbitrageurs. Liquidity discovery reflects this qualitatively different behavior of market participants, when the prices of the assets are tightly related through an arbitrage condition. Liquidity and price discovery are two consequences of arbitrage relations, as by exploiting quote differences the market participants provide liquidity and impact prices.[2] For example, the price of a futures contract is established in relation to the underlying deliverable cash bond by an arbitrage condition, so that, when the two prices diverge, arbitrageurs profit from taking a long position in the cheaper security and a short position in the more expensive security, thus locking in a riskless return. Through these actions, arbitrageurs ultimately play a role of liquidity supplier in both markets. When a shock, whether due to information or liquidity, affects either the cash or the futures market, arbitrageurs will profit from it, if there is a divergence between the prices in the two markets. Hence, the liquidity in the two *closely related* markets has to be strongly related, as well.

The determination of which market reveals the new information first and, consequently, which market adjusts accordingly, resulting in price discovery, is a question that can only be answered empirically. At the same time, the answer will possibly depend on the sampling frequency that is selected for the analysis: the higher the frequency, the greater the likelihood of a discrepancy. To address this question, we exploit the granularity of the MTS Tick-by-Tick data, the most comprehensive data source on the market for European sovereign bonds.

We term the phenomenon of the transmission of liquidity between assets linked by arbitrage as liquidity discovery, describing the process by which information is reflected in market *liquidity*, in a manner analogous to the concept of price discovery, which relates to the reflection of information

[2]For example, stocks and options written on them, bonds and credit default swaps based on them, and cash assets and their corresponding futures contracts, are all cases where the prices of the two assets are connected through arbitrage – if the prices were to deviate too much from the arbitrage condition, traders would take action to bring them back in line.

in *prices*. Specifically, if the information shock resulted first in the flight to quality as well as a significant demand of collateral, liquidity dynamic will show up first in the cash market and then will spill over to the futures market. In this case we would conclude that liquidity discovery takes place there first.

The microstructure of the two markets determines the liquidity discovery process, i.e., the adjustment of liquidity in the two markets to the arrival of new information. One possibility is that the adjustment takes place through changes in the quotes posted by market makers: a widening of the quoted bid-ask spread causes large price changes, accentuating the realized volatility, in turn leading to a correlation between price and bid-ask spread changes. It should be noted that liquidity is also provided by arbitrageurs in addition to market makers. While market makers engage in passive liquidity provision, subject to the constraints imposed by their market-making obligations, arbitrageurs actively exploit any deviation from the arbitrage condition, subject to their own capital constraints. The analysis of liquidity discovery should, perforce, be influenced by the market-making behaviour of the market makers and the limits to arbitrage experienced by the arbitrageurs. These two factors do not necessarily act in the same direction, but may often do so.

To investigate the mechanism of liquidity discovery, it is important that both the cash asset and the futures contract based on it are traded directly (rather than being baskets of assets that are traded individually, for example, as in the case of stock indices) in relatively liquid markets. To investigate this issue it would be useful if high-frequency data were available to discern the speed of response of the liquidity in the two markets to an information shock. The Eurozone sovereign bond markets come close to an ideal laboratory for such an analysis, due to the availability of comprehensive tick-by-tick data for both the cash and the futures market. The richness of the data allows us to determine how the adjustment occurs in the age of algorithmic trading, where market discrepancies are acted on in a matter of seconds, if not milliseconds.

Drawing upon the growing literature on commonality in liquidity, we investigate whether the liquidity in the two markets moves together; thus if, periods of illiquidity in the cash and futures markets would tend to occur contemporaneously. Arbitrageurs need to take this phenomenon into account, which motivates our aim of testing the relationship between shocks to the two markets' liquidity and identifying their driving forces. In order to perform this analysis we use a VAR approach and first we determine the relationship, i.e. the presence of cointegration between the price and the liquidity of the two markets as well as what drives the liquidity. Second, we study the presence of a lead lag relationship of liquidity between the cash and the future market (liquidity discovery). More specifically, we investigate the linkage between the cash and the futures market and the effect of a decline or an increase in liquidity in either market on the cash-futures relationship for Eurozone sovereign bonds.

This paper documents that liquidity discovery primarily takes place in the bond market, in contrast to price discovery mainly happening on the futures market. A shock to liquidity tends to appear first in the bond market and then spills over to the futures market. We further find that cross market arbitrage connections provide significant explanatory power in predicting liquidity. Vector autoregressions on the liquidity of cheapest to deliver (CTD) bonds - futures pairs feature $\overline{R}^2$ values in the order of $80 - 90\%$. Our results quantify the importance of limits to arbitrage as the basis often remains strictly positive in absolute value for several days before converging as the delivery date approaches. The COVID-19 pandemic had a clear impact on the behaviour of arbitrageurs, with breaks in the average price response to the executable basis. Beyond dissecting higher average market volatility and lower liquidity, we document that the convenience yield of the cash instruments surged as the importance of collateral increased, affecting price and liquidity discovery dynamics (see, among others, Adrian et al., 2019). As marcoeconomic conditions suddenly deteriorated, financial markets had to process huge changes in the demand and supply in assets in a very short time. Especially the sovereign bond markets, usually considered safe havens, were affected. Bond yields in the US and European sovereign bond markets soared in March 2020 until the intervention of the central banks. In contrast to the 'dash for cash´ that ocurred on the US treasury market at the onset of the pandemic, we find evidence in line with a 'dash for collateral,´ especially on the German and French market. The Italian market, on the other hand, is caracterized by a price drop that is due to an increase in sovereign risk.

We organize this paper as follows. Section 2 develops testable hypotheses and outlines our empirical strategy. Section 3 describes the data, and Section 4 provides empirical results. Section 5 offers concluding remarks.

2 Methodology

Prices The prices of the futures and the underlying bonds are bound by a tight arbitrage condition as discussed earlier. Hence, in line with the previous literature, we investigate whether the futures market is the one in which new information is first revealed, with the cash market adjusting to this movement with a lag. We investigate this price discovery process using a cointegration framework, allowing the data to indicate the cointegration rank and space, thus statistically testing whether a net-zero-basis hypothesis, predicted by the arbitrage argument, is supported by the data. The model we estimate is as follows:

$$\begin{pmatrix} \Delta P_{cash,t} \\ \Delta P_{Fut,t} \end{pmatrix} = \alpha\beta' \begin{pmatrix} P_{cash,t-1} \\ P_{Fut,t-1} \\ 1 \end{pmatrix} + \sum_{i=1}^{p} \phi_i \begin{pmatrix} \Delta P_{cash,t-i} \\ \Delta P_{Fut,t-i} \end{pmatrix} \quad (1)$$

where $\Delta P_{cash,t}$ is the change in the price of the cash market, $\Delta P_{fut,t}$ is the change in the price in the (conversion-factor-adjusted) futures market. The analysis of the prices in the two markets also allows us to investigate the patterns in the basis B_t over time, i.e., the difference between the price of the underlying deliverable cash bonds and the futures price (corrected by the conversion factor). We expect β, the co-integration vector, to be $(1, -1)$, hence supporting the arbitrage condition, and we expect α to indicate that most price discovery happens on the futures market.

Liquidity We aim to investigate the dynamic inter-relation of the liquidity in the cash and futures markets. To distinguish between long- and short-term adjustments, we analyze this relationship at a daily level (in levels) and at the intra-day level (in differences). As discussed above, the liquidity in the two markets is substantially different, with the futures market being much more liquid, while the liquidity in the cash bond market is distributed over several cash bonds with different maturities and coupons. However, since the cash bond is the security underlying the futures market, we expect the liquidity in the cash bond market to have an influence on the liquidity of the futures contract, and vice versa. We also expect that , given that Italian market makers in the cash market are monitored by the *Tesoro* according to their presence at the best bid and offer prices over time, they have a clear incentive to keep the price aligned to the best quotes.

We need to distinguish between a change in liquidity that comes from a change in the information set available to investors, which will likely move from the futures market to the cash market, and shocks to liquidity that originate purely from changes in the demand for the cash bonds, such as the ECB interventions, which we expect to move from the cash to the futures market. One also needs to consider the behavior of arbitrageurs that is largely affected by the level of the basis, the level of liquidity and its volatility in both markets; these characteristics of liquidity have an important influence on investors' ability to implement arbitrage actions. To address this issue, we estimate a VAR at a daily frequency, using the level of the basis and liquidity measures in the two markets as endogenous variables, and consider the impulse response functions in order to understand the overall effect of one variable on the others.

Formally, the model we investigate is:

$$\begin{aligned} QS_{cash,t} =& \alpha + \sum_{i=1}^{p} \beta_i QS_{cash,t-i} + \sum_{i=1}^{p} \gamma_i QS_{future,t-i} + \sum_{i=1}^{p} \delta_i B_{t-i} \\ QS_{fut,t} =& \alpha + \sum_{i=1}^{p} \beta_i QS_{cash,t-i} + \sum_{i=1}^{p} \gamma_i QS_{future,t-i} + \sum_{i=1}^{p} \delta_i B_{t-i} \end{aligned} \quad (2)$$

where $QS_{cash,t}$ and $QS_{fut,t}$ represent, respectively, the *Quoted Spreads* in the cash and futures markets, and B_t represents the basis. The level of the basis implies potential arbitrage opportunities between the two markets, and therefore potential incentives for arbitrageurs to exploit these opportunities. In principle, if the basis were zero, this analysis would capture just the stickiness of the liquidity adjustment.

However, the analysis at the daily frequency focuses on both the long-run (interday) and short-run (intraday) adjustments of the basis and liquidity in the two markets. The adjustment mechanisms may be different depending on the frequency of trading; intraday adjustments of the basis and the spillover effects of liquidity between the two markets may be different from those between days. Formally, the intraday model we investigate is:

$$\begin{aligned}\Delta QS_{cash,t} =& \alpha + \sum_{i=1}^{p} \beta_i \Delta QS_{cash,t-i} + \sum_{i=1}^{p} \gamma_i \Delta QS_{future,t-i} + \sum_{i=1}^{p} \delta_i \Delta B_{t-i} \\ \Delta QS_{fut,t} =& \alpha + \sum_{i=1}^{p} \beta_i \Delta QS_{cash,t-i} + \sum_{i=1}^{p} \gamma_i \Delta QS_{future,t-i} + \sum_{i=1}^{p} \delta_i \Delta B_{t-i}\end{aligned} \tag{3}$$

where $\Delta QS_{cash,t}$ and $\Delta QS_{fut,t}$ represent, respectively, the changes in the *Quoted Spreads* in the cash and futures markets, and ΔB_t represents the change in the basis. It is clear that changes in the basis imply changes in the arbitrage relationship between the two markets. Once this effect is controlled for, the remaining component can be attributed to shocks to liquidity due to trading, funding liquidity, or other causes that do not directly affect the relative pricing of the futures contract and the underlying cash bond.

3 Data

We focus on MTS high frequency data on French, German, and Italian sovereign bonds between 2019 and 2021 and on futures contract written on them. To better appreciate different regimes in the data, we organize the analysis around three subsamples, including data for 2019, 2020, and 2021, respectively. The MTS system is a quote-driven electronic limit order interdealer market offering a comprehensive representation of the European Government Bond (EGB) market.

Bond characteristics such as coupons, tenor, and so forth, are available in the MTS references files, and the limit order book can be reconstructed by the MTS Tick-by-Tick data. After removing proposals with zero quantity or prices, we sample the limit order book at the five-minutes resolution.[3] To avoid noise at market open and closure, we summarize the information content of the book from 9.00 am to 17.00 pm within each trading day. As is standard, we condense the huge amount of information through all the active proposals at the five minutes breakpoints. For instance, we would sample a proposal alive between 9:04:45 and 9:05:10 because it is active at 9:05:00.

We primarily focus on the best five quotes on the buy and sell side of the market, and their respective quantities, for each bond of interest. Daily data are obtained for comparison and robustness, by averaging intraday observations. The source of futures data referenced on the cash market is Revinitiv Tick History, from which we gather prices, spreads, and volumes, among others. We take the delivery calendar and formulas for conversion factor calculations from the EUREX website.[4] A delivery date is defined as the tenth calendar day of the respective quarterly month, if this day is an exchange day; otherwise, the exchange day immediately succeeding that day. The conversion factor is a bond-specific proportion of the price that the bond would have at delivery if the term structure was flat at 6%.[5] We report the resulting cheapest to deliver bonds, and futures conversion factors for each delivery date in Table 1. In general, when interest rates are low the CTD corresponds to the bond with the shortest duration. We further construct the net basis between futures and bonds, defined as the minimum value of the difference between the forward price of a bond and its conversion factor adjusted futures price, $FP(it) - F_t \cdot CF_i$. The remainder of our analysis focuses on the nearest-delivery futures contract–CTD bond pair.

3.1 Descriptive Statistics

While economic growth plummeted into abysmal depths at the onset of the COVID-19 pandemic in 2020, 2019 and 2021 were characterized by comparatively lower volatility. Table 2 presents summary statistics of prices and best bid-ask spreads of French, German, and Italian futures and

[3] We apply other standard data cleaning procedures to remove missing observations and harmonize proposals expressed in seconds with those formatted in milliseconds.

[4] See https://www.eurex.com/ex-en/data/clearing-files/notified-deliverable-bonds-conversion-factors

[5] See also Pelizzon et al. (2020) and references therein.

cheapest to deliver sovereign bonds during 2019, at the daily and five-minutes resolution (Annex I). Bunds CTD cost on average €1.0597 per thousand euros of face value, while the average midquotes of the French *obligations assimilables du trésor* and the Italian *buoni poliennali del tesoro* are €124.63 and €109.74, respectively. Italian bond prices feature a mild right skeweness during 2019, and a comparison of daily and intraday data reveals that daily aggregation is sufficient for the first two moments of the distribution. Consistent with the interconnection between credit risk and market liquidity (Ericsson and Renault, 2006), there are significant differences between the liquidity of Italian government bonds and the German ones, with the spread of French obligations in between. Interestingly, the German *deutsche bundesrepublik*'s 4 percentage points daily standard deviation in quoted spreads masks a much higher figure at the 0.53 five-minutes resolution. Since futures contract are not conversion-adjusted, a between-country unconditional comparison of prices is not informative, and a formal comparison across markets is deferred to Section 4. As expected, futures contracts require less capital and are more liquid than the underlying cash markets. Annex II of Table 2 evaluates the same aggregates in 2020. A qualitative comparison shows how the turmoil caused by the pandemic increased bid-ask spreads in the cash market by some 4 percentage points, i.e., one standard deviation away from the average illiquidity in the previous year. Observing the recent 2021 sample in Table 2, Annex III, an unconditional reversion to standard levels of prices and market liquidity characterizes data spanning 2021:Q1 to Q2. However, in the 2021 sample Italian sovereign bonds on MTS are on average surprisingly about twice as liquid as German ones. Interestingly, the liquidity of the French market still remained in between the German and the Italian market.

Prices Figures 1, 2, and 3 illustrate the daily time series behavior of French, German and Italian adjusted futures and cheapest to deliver bonds during 2019, 2020 Q1:Q3, and 2021 Q1:Q2, respectively. After delivery dates in which cheapest to deliver cash instruments change, along with their price and conversion factor, prices are reported in different colors. As observed by Brunnermeier and Pedersen (2009), and recently tested by Hazelkorn et al. (2020), the absolute value of the basis is particularly high at times where funding liquidity is more constrained and dealers are more risk averse, which correspond to high volatility regimes. A clear illustration of the phenomenon is offered by the peak of the COVID-19-induced financial turmoil in March 2020, at times when arbitrageurs found higher barriers to profit from mispricing. The behavior observed is rather similar between France and Germany, with a significant increase in the price during March 2020 (and therefore a significant decrease of the yield) indicating a flight to quality and an increase in the demand of these assets. This pattern is confirmed both in the cash and in the futures market. It is interesting to note that the pattern of the French and the German market is a "dash for collateral" as stressed in Moench et al. (2021), the opposite of the "dash for cash" phenomenon that has been observed in the US Treasury market during March 2020 documented by Duffie (2020) among others. On the other side, it is interesting to observe the reduction in the price of the Italian bond in March 2020, due to the increase of sovereign credit risk (not a dash for cash phenomenon as in the US Treasury). Therefore, the outbreak of Covid-19 caused asymmetric responses across sovereign yields. Sovereign yields started to diverge in February 2020, mainly driven by Italian yields. Italian yields more than doubled in the month preceding 18 March 2020. To improve the economic and inflation outlook, and to stabilize markets, the ECB announced its PEPP on 18 March 2020 (see also Corradin et al., 2021). Clearly, all the series involved display a pattern of gradual convergence of the vertical distance between adjusted futures price and CTD bond, i.e., the basis, to zero as the delivery date approaches (see also Barth et al., 2021, for a discussion on the cash-futures disconnect in the US market). This pattern has a natural interpretation in that as uncertainty resolves, the risk premia of the carry trade gradually dwindle.

Market Liquidity Figure 4 shows the time series of quoted bid-ask spreads on the CTD (top panel) and futures contract (bottom panel) for French, German, and Italian sovereigns, respectively in green, blue, and black. Across markets, liquidity is one order of magnitude higher in the futures market (see also Table 2). Clearly, futures positions require a margin thus involving less financing constraints than trades in the underlying. Moreover, futures are typically closed before delivery, entering in the opposite trade to the original one. As a repercussion of the high trading volume, the market is very liquid. In the cash market, liquidity is comparable across countries (top panel). Conversely, FGBL futures written on German instruments are more liquid than FBTP contracts referencing Italian public debt, with FOAT futures contracts on French obligations in between (bottom panel).

Importantly, illiquidity in the futures market (bottom panel in Figure 4) regularly spikes before the delivery dates, to then revert to the mean. This finding is robust to considering results at the higher five-minutes resolution, displayed in Figure 5, and across all the three French, German, and Italian segments of the market considered. Rephrasing, EUREX market makers require higher compensation in terms of bid-ask spreads in proximity of the delivery dates, whilst MTS markets are unaffected. Since asymmetric information is unlikely to be the driving force for a trade approaching convergence, a strong candidate to explain spreads behavior is that reduced liquidity simply reflects inventory availability. In the run-up to delivery dates, it might well be that a lower proportion of futures remains available to participants on the brink to avoid delivery by entering the opposite agreement.

As widely noted by market watchers, 2020 shows yet a markedly different picture in terms of spreads (see also Duffie, 2020, for a discussion of the effects of the COVID-19 pandemic on the US Treasury market). Figure 6 shows the liquidity of CTD bonds and futures traded on MTS and EUREX, at the daily and five-minutes resolution, for three series corresponding to French *obligations assimilables du trésor*, German *deutsche bundesrepublik*, and Italian *buoni del tesoro poliennali*. Interestingly, we do not observe the asymmetric responses across liquidity as we observed for sovereign yields (and prices). During this risk-off regime, heightened risk aversion persistently increased illiquidity starting from the end of February 2020. Illiquidity further exhibits a strong spike in the wake of the European Central Bank Pandemic Emergency Purchase Programme (PEPP), an overall envelope of €750 billion announced on March 18^{th}. Along with a gradual reversion to orderly markets, we again note a spike in illiquidity in the futures market in the neighborhood preceding the delivery date on June 10^{th} 2020. Figure 7 shows that these patterns are largely consistent when focusing on a higher resolution.

4 Results

Price Discovery Table 3 reports the first-pass test of cointegration analysis, highlighting a stark connection between the futures and cash prices throughout sample periods and frequencies. The hypothesis of a cointegrating rank less than or equal to one is consistently rejected in favour of its competing alternative. Clearly, the rank of the product $\alpha\beta$ equals two, paving the way for the estimation of cointegrating relations. Indeed, the non-arbitrage condition allows to normalize $\beta_{cash} \approx -\beta_{fut}$ and rewrite Equation 1 in an intuitive format.

$$\begin{pmatrix} \Delta P_{cash,t} \\ \Delta P_{fut,t} \end{pmatrix} = \begin{pmatrix} \alpha_{cash} \\ \alpha_{fut} \end{pmatrix} (P_{cash,t-1} - P_{fut,t-1} + Const.) + \sum_{i=1}^{p} \phi_i \begin{pmatrix} \Delta P_{cash,t-i} \\ \Delta P_{fut,t-i} \end{pmatrix} \tag{4}$$

Hence, a comparison of the magnitude of α_{cash} and α_{fut} is informative on which market reacts more strongly to the executable basis over the frequency of estimation.[6]

Table 4 reports the estimates Equation 1 in the cross-section of the two countries and over the time dimension spanning 2019 to 2021, both at the daily and at the five minutes resolution. All coefficient estimates are statistically significant at the 1% level of confidence. Let us focus first on Panel A, showing the analysis on the 2019 sample. Throughout, the β coefficient on futures price is extremely close to minus one, as one would expect as a result of the tight arbitrage linkage between futures and cash markets. Most interesting is the estimated α vector, revealing that the basis is most strongly acted upon in the futures market at both frequencies and in both markets. To be precise, in the Italian market the average change in the futures price is €0.158 after five minutes of a deviation from the long-run equilibrium, and €0.528 when considering

[6] We direct the reader to Johansen (1988) and Lütkepohl (2005) for standard references on cointegration analysis.

daily intervals. Conversely, the bond price experiences a change of €0.124 and €0.417 at the five minutes and daily resolutions, respectively. The German market conveys the same message, even stronger in magnitude, with $\hat{\alpha}^{DE}_{fut} = (0.185, 1.26)$ and $\hat{\alpha}^{DE}_{cash} = (0.056, 0.618)$ at the five minutes and daily frequencies, respectively. Estimates from the French market are aligned, with $\hat{\alpha}^{FR}_{fut} = (0.39, 2.26)$ and $\hat{\alpha}^{FR}_{cash} = (0.28, 1.82)$, where again the short-term adjustment coefficient estimate of futures contract is in absolute value larger than the corresponding figure for the cash market. Overall, price discovery consistently takes place on the futures market, which involves less financing constraints than trades in the underlying.

The COVID-19 pandemic brings about a dash for collateral which colours the cash market with a convenience yield.[7] The risk-off induced repricing changed profoundly the connection between markets in 2020, as shown in Panel B of Table 4. While at the five minutes frequency price discovery is strongly exerted by futures prices in the Italian, French, and German case, at the daily resolution the α estimated coefficient on the cash market is in absolute value larger highlighting a stronger reaction of the bond price to temporary deviations from the long-run equilibrium value of the executable basis. In general, with rising risk aversion the role of the bond market as safe haven gained importance relative to speculative activity to close the basis. Thus, the leading role of the cash market is consistent with macroeconomic forces, while in the microstructure of the high-frequency trades futures contracts continue to react starkly to impound in prices news about the basis.

The granularity of our estimation approach allows us to trace neatly how the events unfold in the time dimension. The analysis in the 2021 subsample – which we report in Panel C of Table 4) – indeed confirms that in normal times price discovery takes place in the futures market, consistently across all three the French, German, and Italian samples and through frequencies, with $\hat{\alpha}^{FR}_{fut} = (0.36, 0.63)$, $\hat{\alpha}^{DE}_{fut} = (0.025, 0.45)$, and $\hat{\alpha}^{IT}_{fut} = (0.014, 0.156)$ in five-minute and daily estimates, respectively.

A longitudinal appreciation of the α coefficient estimates reveals a stable decrease through

[7] See https://voxeu.org/article/market-liquidity-european-sovereign-bonds-during-covid-19-crisis

time, with a gradual convergence to lower levels of price adjustments, with increased price discovery accompanying the penetration of high frequency traders (HFT) in the market. Overall, Table 4 has powerful implications for investors seeking to time the market. Indeed, the results consistently show that in normal markets the futures contract is the fastest to react to temporary deviations from the equilibrium level of the executable basis, so that a temporary divergence between the two legs of a carry trade has predictive information on which market will react more strongly.

Table 5 completes the picture on cointegration analyisis by estimating the lag order p of the short term adjustment coefficients, the last addendum in Equation 1. We report estimates at the five-minute frequency, since at the daily level the number of significant lags is practically always zero, again highlighting the intraday nature of the price discovery phenomenon. The maximum number of lags is estimated by Akaike information criterion, but a Bayesian penalty function would lead to very similar conclusions. Consistent with the picture offered by the cointegrating restrictions, we see the number of significant lags gradually shrink over time, as market velocity grows faster.

Liquidity Discovery Illiquidity spillovers have a natural interpretation. Suppose that liquidity is shocked in one of the two markets connected by the activity of arbitrageurs. An increase in liquidity reduces the costs of arbitraging away price differences, thus increasing the activity on both markets. Vice versa, the arbitrage connection is impaired when liquidity dries up in one of the two markets, in turn reducing liquidity in the companion markets, as buy-side investors require higher compensation in terms of executable basis to enter both legs of the arbitrage position.

This paragraph brings the statistical models of Section 2 to the data; specifically, Table 6 presents the results of estimating Equation 2 at a daily frequency, and Equation 3 at the five-minutes resolution, on CTD-futures pairs separately by country. For completeness, we also report the coefficients on the regression of the basis on liquidity – as captured by quoted spreads – in the cash and futures markets.

Liquidity has a strong autoregressive component, with several significant lags both at the daily frequency, for the model in levels, and in the intraday, for the model in first differences. In detail, the autoregressive coefficient is the strongest in both the cash regression and the futures regression. Consistent with the results on cointegration, the basis shows a more persistent reaction to the futures market in normal times, while the opposite generally emerges for the 2020 sample. Overall, liquidity discovery appears to be a largely intraday phenomenon, as the number of lags selected at higher frequencies – estimating a model in first differences – is always higher compared than in the daily case. The adjusted R^2 of these regressions is particularly large, reaching peaks of 0.99 which confirm that liquidity is strongly predictable, and that spreads in the cash market have lead information content for liquidity in futures market, and vice versa.

We use the explanatory power of these models to simulate impulse response functions (IRFs) of best bid and ask spreads in MTS and EUREX markets, in Figures 10, 11, and 12. Specifically, we plot the impulse response functions of liquidity to a one-standard deviation shock in the quoted spreads of the bond and the futures, and the basis. We confine the exercise on the daily model in levels of Equation 2, whose advantage rests in interpretability, again stratifying the analysis by year. In 2019, a shock on liquidity is mostly persistent in the same market – over the first few days in the MTS cash market, where the half-life of the shock is about 2 days, and for a much longer horizon in EUREX markets (see IRFs in Figure 10), for all three the French market (OAT and FOAT), the Italian (BTP and FBTP), and the German ones (DBR and FGBL). Figure 11 reveals the effects of the coronavirus pandemic on the transmission of illiquidity to be large, although clouded by statistical uncertainty. Once again, in turbolent times the role of the cash market gains prominence, as its primary role transitions to a market for safe collateral. The analysis on 2021 Q1:Q2 shown in Figure 12 confirms the pattern found in 2019, with the remarkable finding of a positive effect on futures liquidity (i.e., a negative IRF of the spread) resulting from the basis (see the first subpanel on the left in the IRFs of Futures Contracts), starkly confirming the findings on price discovery; namely, shocks to the basis increase the activity and liquidity in the futures market to arbitrage away price differences. Overall, the VAR evidence on liquidity discovery is suggestive of the important role of cash markets to forecast futures contracts' liquidity.

5 Conclusion

This paper thoroughly investigates price and liquidity patters in high frequency MTS and EUREX markets. We focus on the cheapest to deliver bond and closest futures pairs, tightly connected by arbitrageurs' carry trades, and analyze the impact of this relation on price and liquidity discovery, namely the transmission of innovations in both variables across markets. To better appreciate different regimes in the data and evaluate parameter stability, we run a battery of statistical models through different samples both in the time series and in the cross-section at different resolutions. Overall, several interesting findings appear to be robust to perturbations of the empirical design. First, price discovery occurs on the futures market, where prices react more strongly to changes in the executable basis. Second, the basis gradually converges to zero as the delivery dates approach and uncertainty resolves. Third, liquidity spillovers find strong empirical support, with forecasting signals mostly originating in the cash market. Fourth, in the futures market illiquidity regularly spikes before delivery dates. Fifth, limits to arbitrage are significant even in the most liquid European markets, as the basis remains different from its equilibrium level for several consecutive days. Finally, liquidity is strongly predictable and cross-market arbitrage connections add significant explanatory power.

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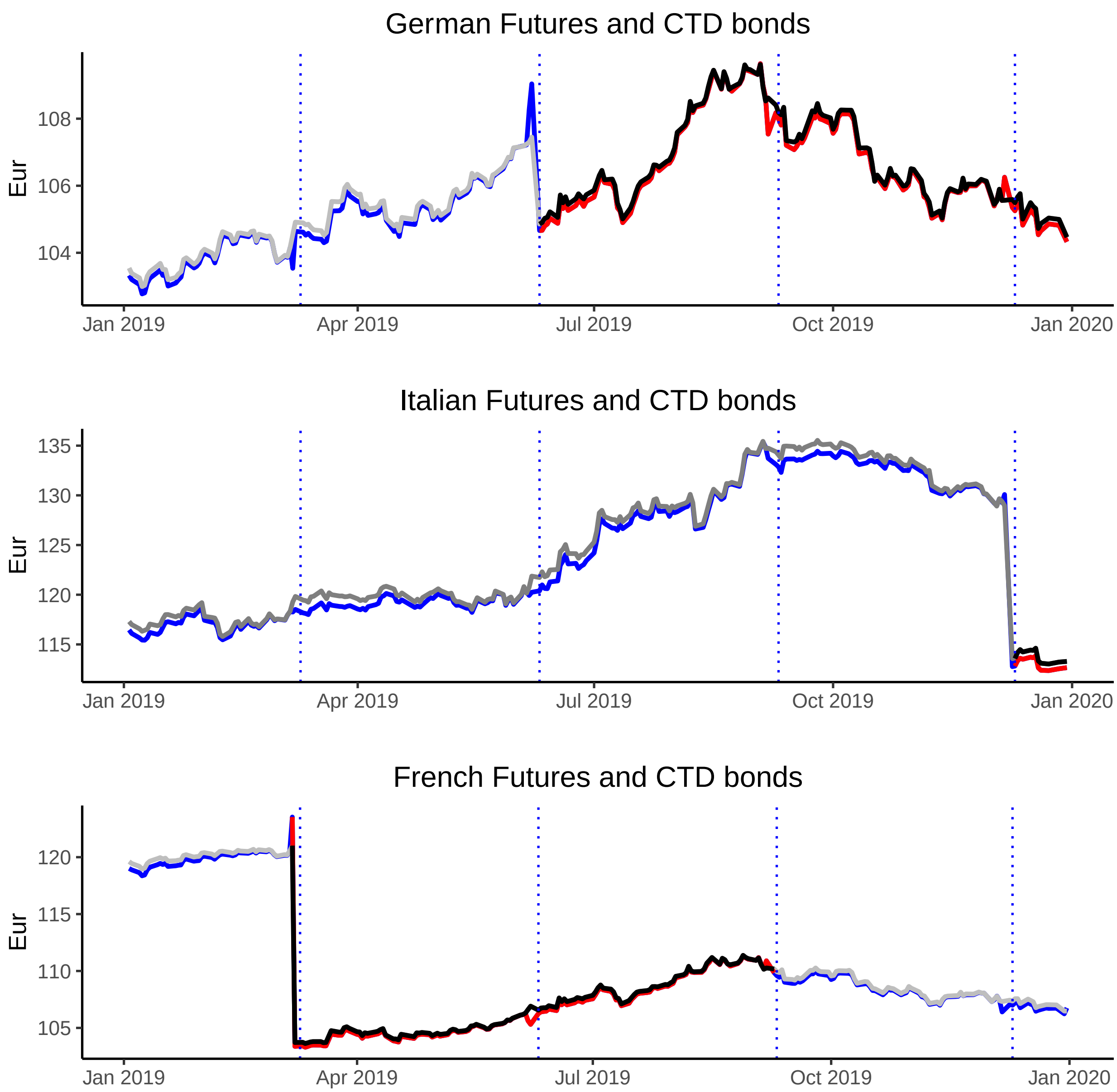


FIGURE 1: **Cash and Futures Markets in 2019**: This figure plots futures and cheapest to deliver bonds measured at the daily resolution. Futures are adjusted by their conversion factors. Black and blue lines denote German, Italian and French futures contracts, respectively, and color changes track a switch in the CTD bond. The data are obtained from the MTS and EUREX markets and the sample spans 01 January 2019 to 31 December 2019.

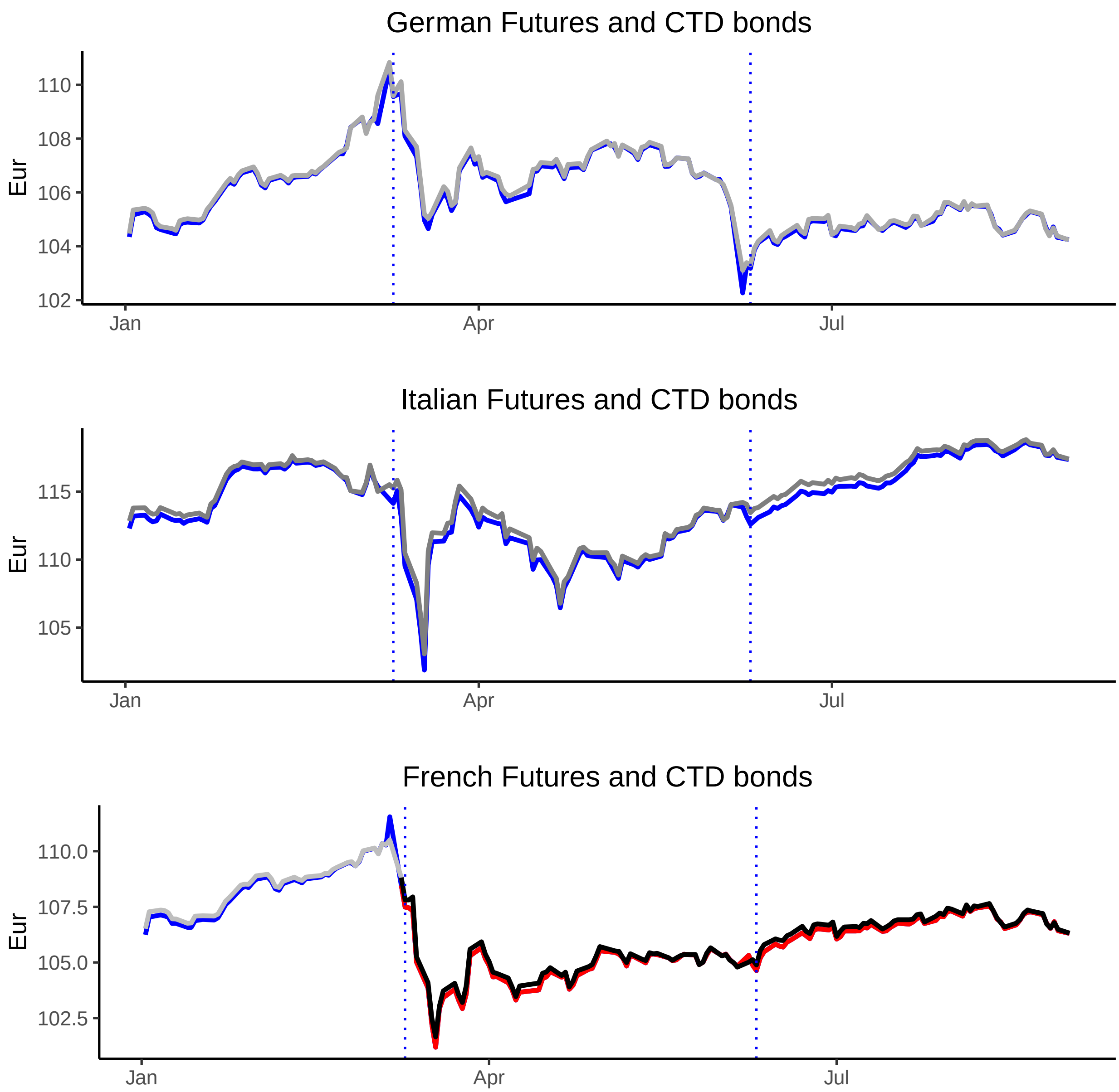


FIGURE 2: **Cash and Futures Markets in 2020**: This figure plots futures and cheapest to deliver bonds measured at the daily resolution. Futures are adjusted by their conversion factors. Black and blue lines denote German, Italian and French futures contracts, respectively. The data are obtained from the MTS and EUREX markets and the sample spans 01 January 2020 to 09 September 2020.

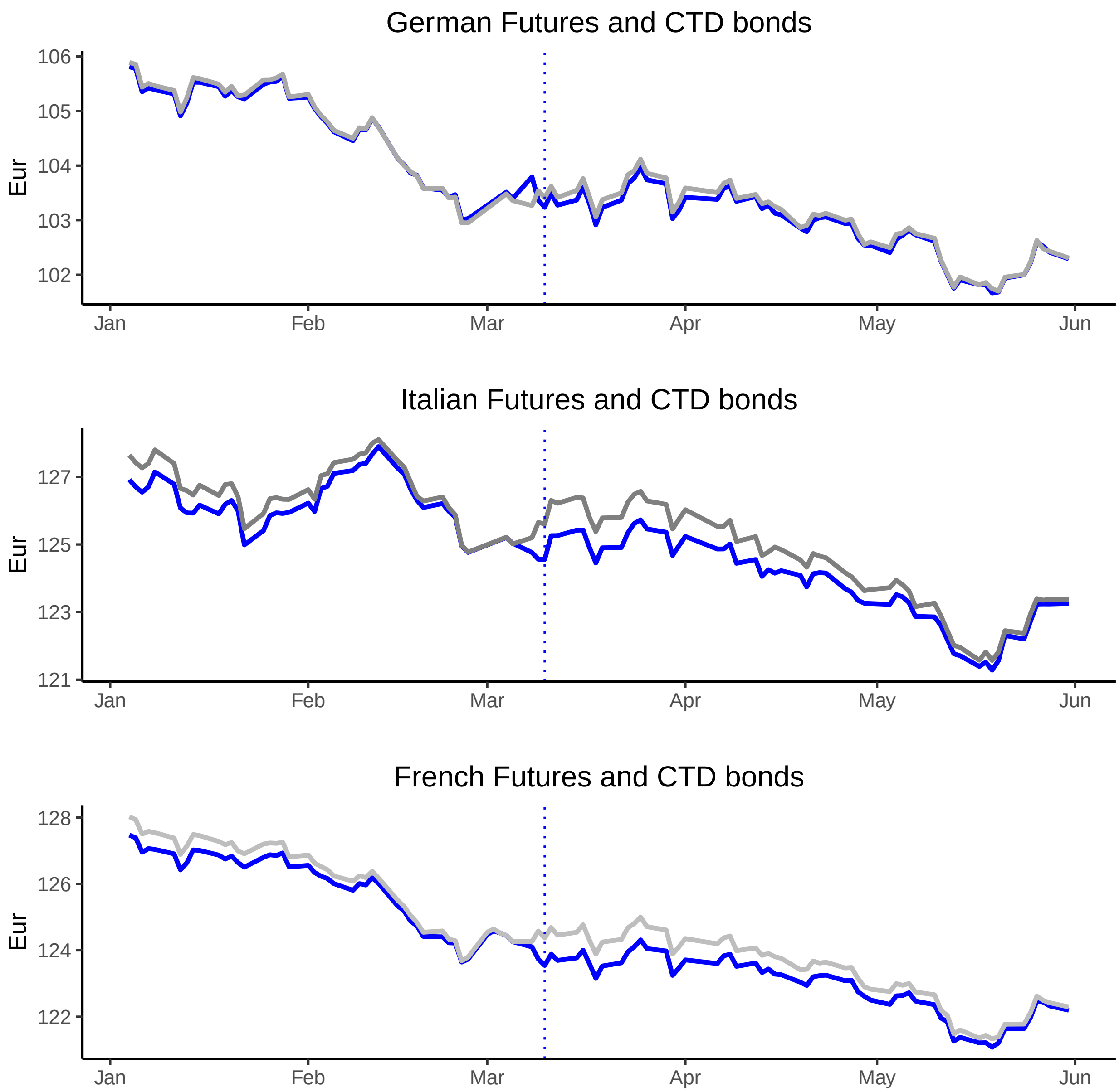


FIGURE 3: **Cash and Futures Markets in 2021**: This figure plots futures and cheapest to deliver bonds measured at the daily resolution. Futures are adjusted by their conversion factors. Black and blue lines denote German, Italian and French futures contracts, respectively. The data are obtained from the MTS and EUREX markets and the sample spans 01 January 2021 to 01 June 2021.

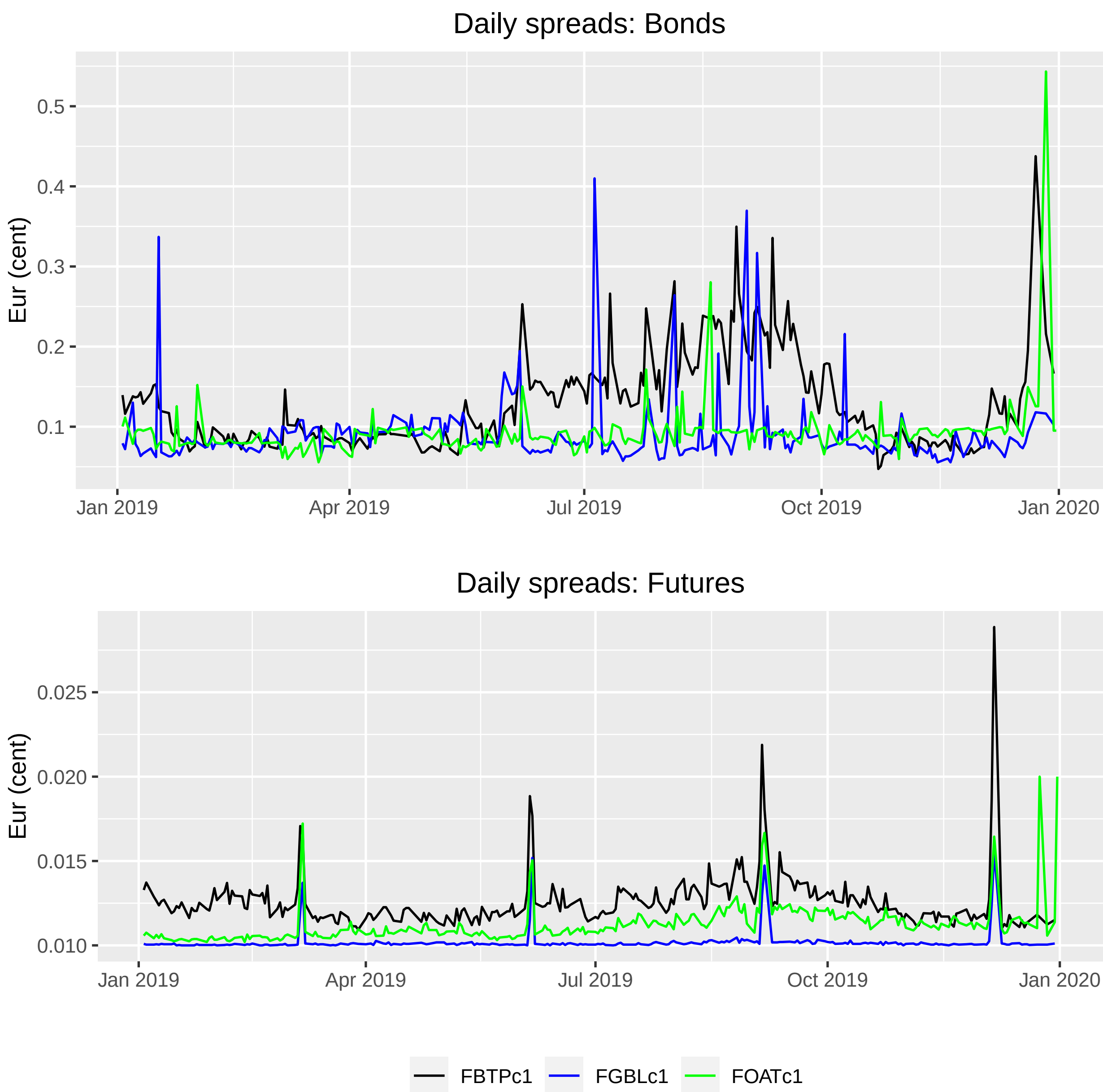


FIGURE 4: **Bid-Ask Spreads in 2019**: This figure plots the quoted bid-ask spread of futures and bonds measured in percentage points of Euro at the daily frequency. The top panel reports values for CTD bonds and the bottom panel for futures contracts. Black, blue, and green lines indicate Italian, German, and French contracts, respectively. The data are obtained from the MTS and EUREX markets and the sample spans 01 January 2019 to 31 December 2019.

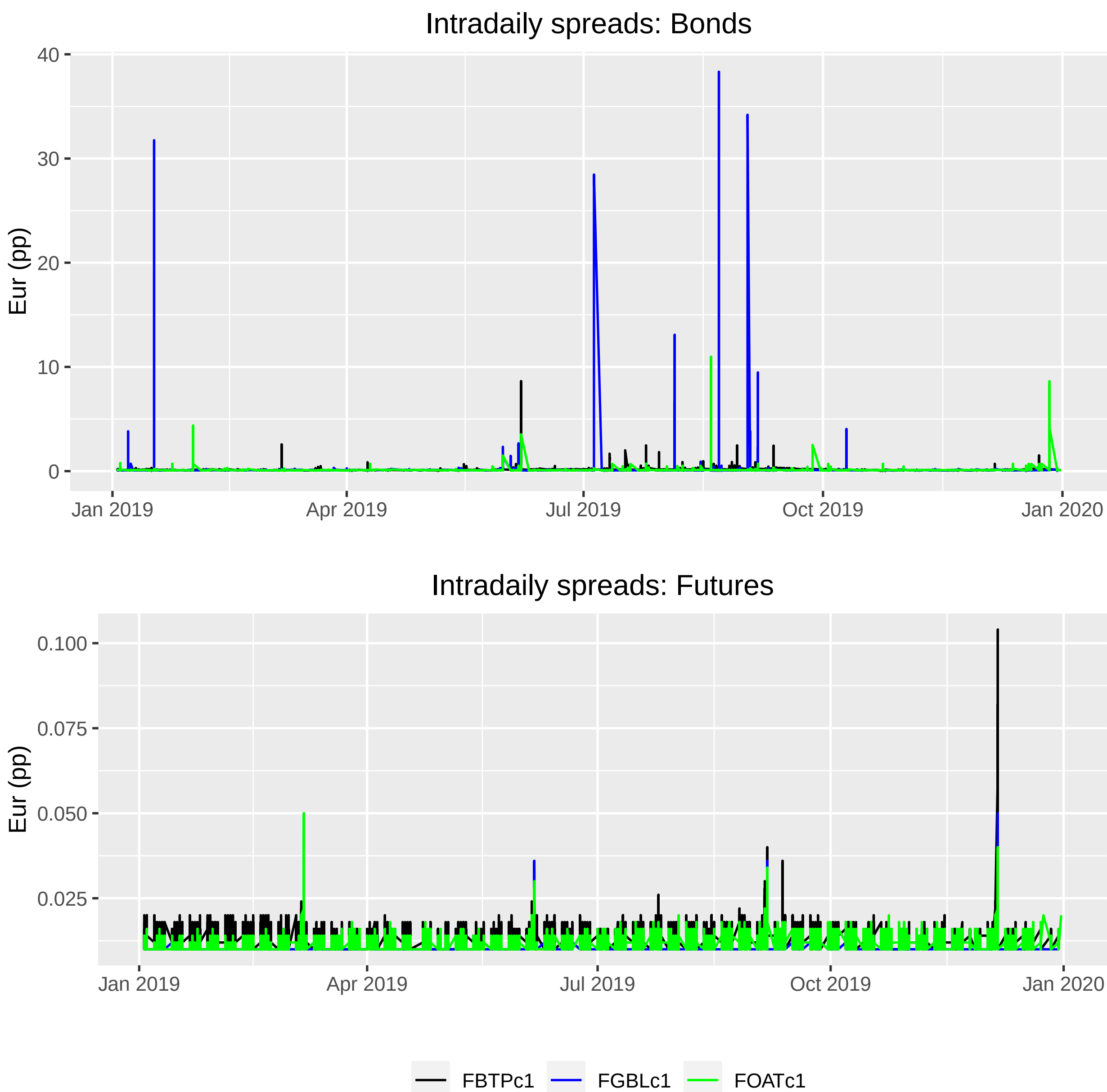


FIGURE 5: **Bid-Ask Spreads in 2019**: This figure plots the quoted bid-ask spread of futures and bonds measured in percentage points of Euro at the five minutes resolution. The top panel reports values for CTD bonds and the bottom panel for futures contracts. Black, blue, and green lines indicate Italian, German, and French contracts, respectively. The data are obtained from the MTS and EUREX markets and the sample spans 01 January 2019 to 31 December 2019.

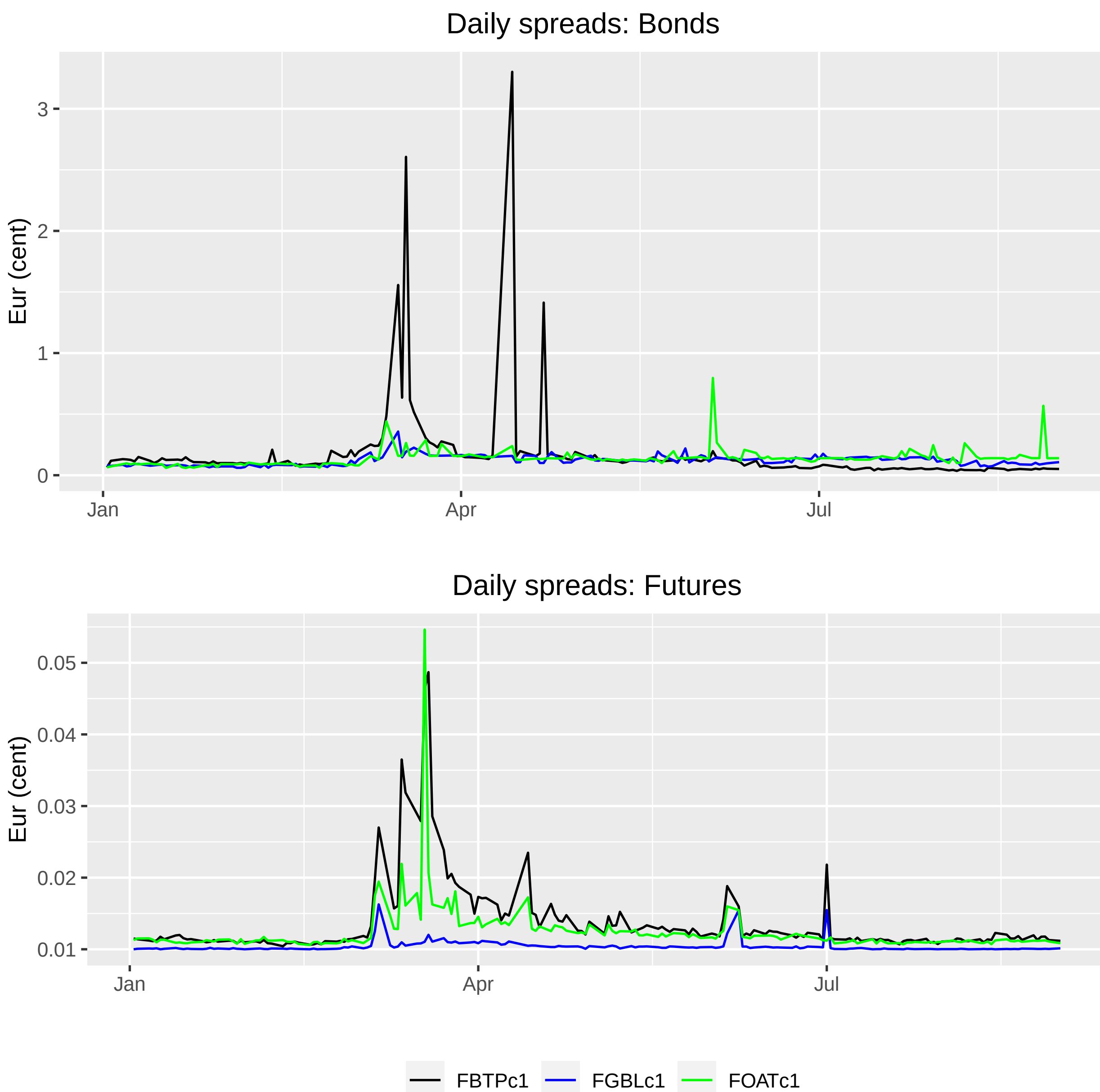


FIGURE 6: **Bid-Ask Spreads in 2020**: This figure plots the quoted bid-ask spread of futures and bonds measured in percentage points of Euro at the daily frequency. The top panel reports values for CTD bonds and the bottom panel for futures contracts. Black, blue, and green lines indicate Italian, German, and French contracts, respectively. The data are obtained from the MTS and EUREX markets and the sample spans 01 January 2020 to 09 September 2020.

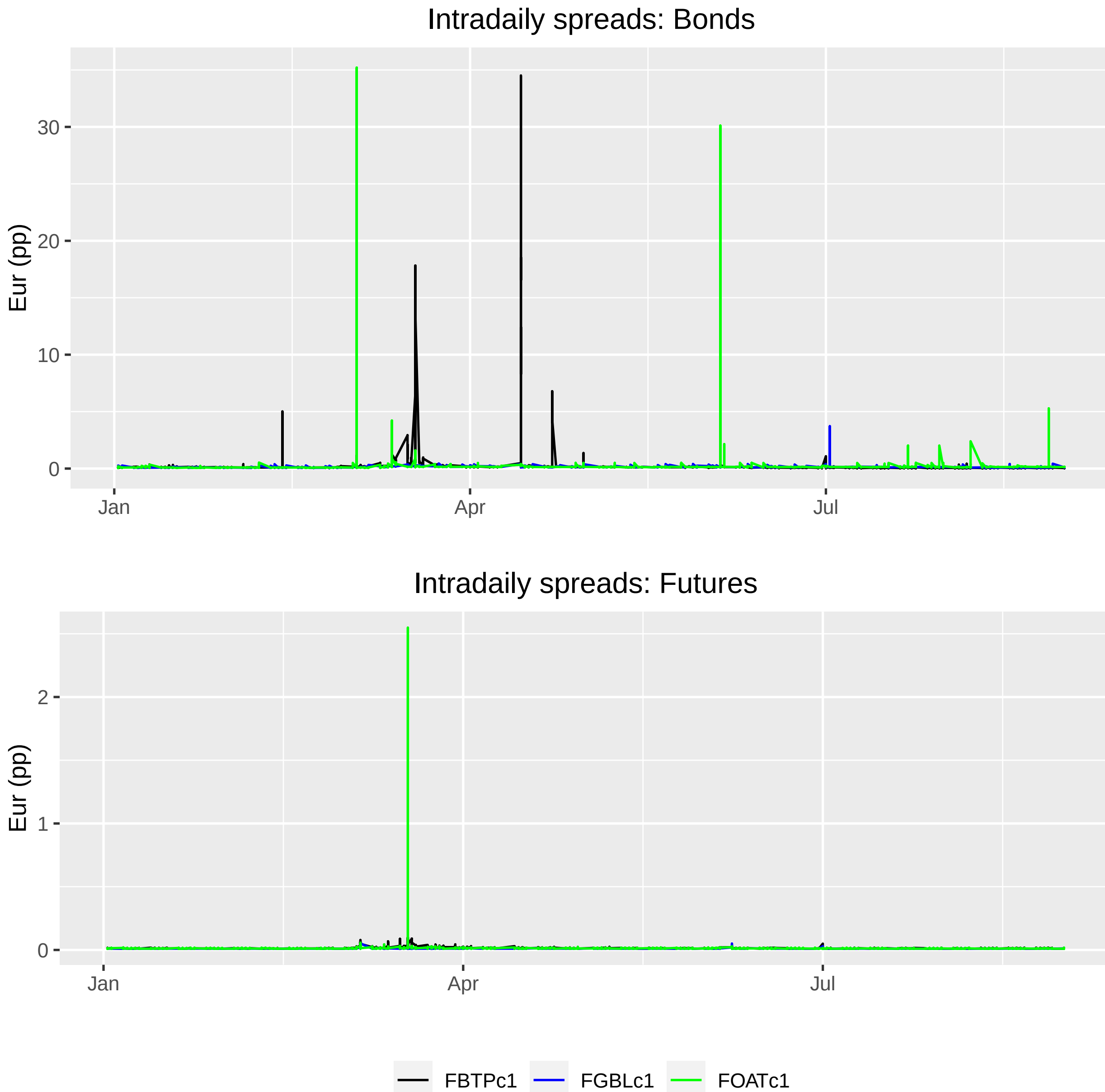


FIGURE 7: **Bid-Ask Spreads in 2020**: This figure plots the quoted bid-ask spread of futures and bonds measured in percentage points of Euro at the five minutes resolution. The top panel reports values for CTD bonds and the bottom panel for futures contracts. Black, blue, and green lines indicate Italian, German, and French contracts, respectively. The data are obtained from the MTS and EUREX markets and the sample spans 01 January 2020 to 09 September 2020.

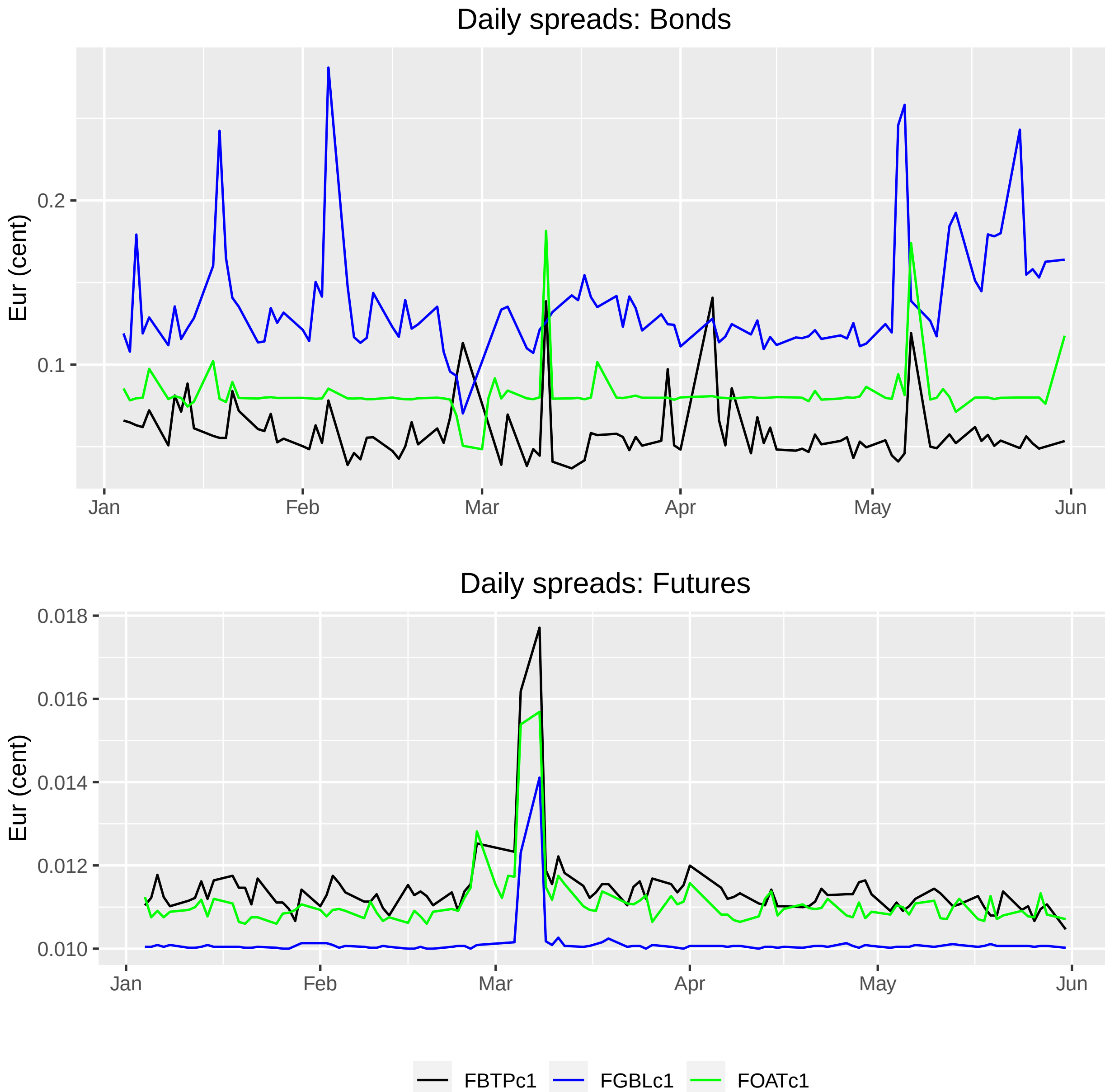


FIGURE 8: **Bid-Ask Spreads in 2021**: This figure plots the quoted bid-ask spread of futures and bonds measured in percentage points of Euro at the daily frequency. The top panel reports values for CTD bonds and the bottom panel for futures contracts. Black, blue, and green lines indicate Italian, German, and French contracts, respectively. The data are obtained from the MTS and EUREX markets and the sample spans 01 January 2020 to 01 June 2021.

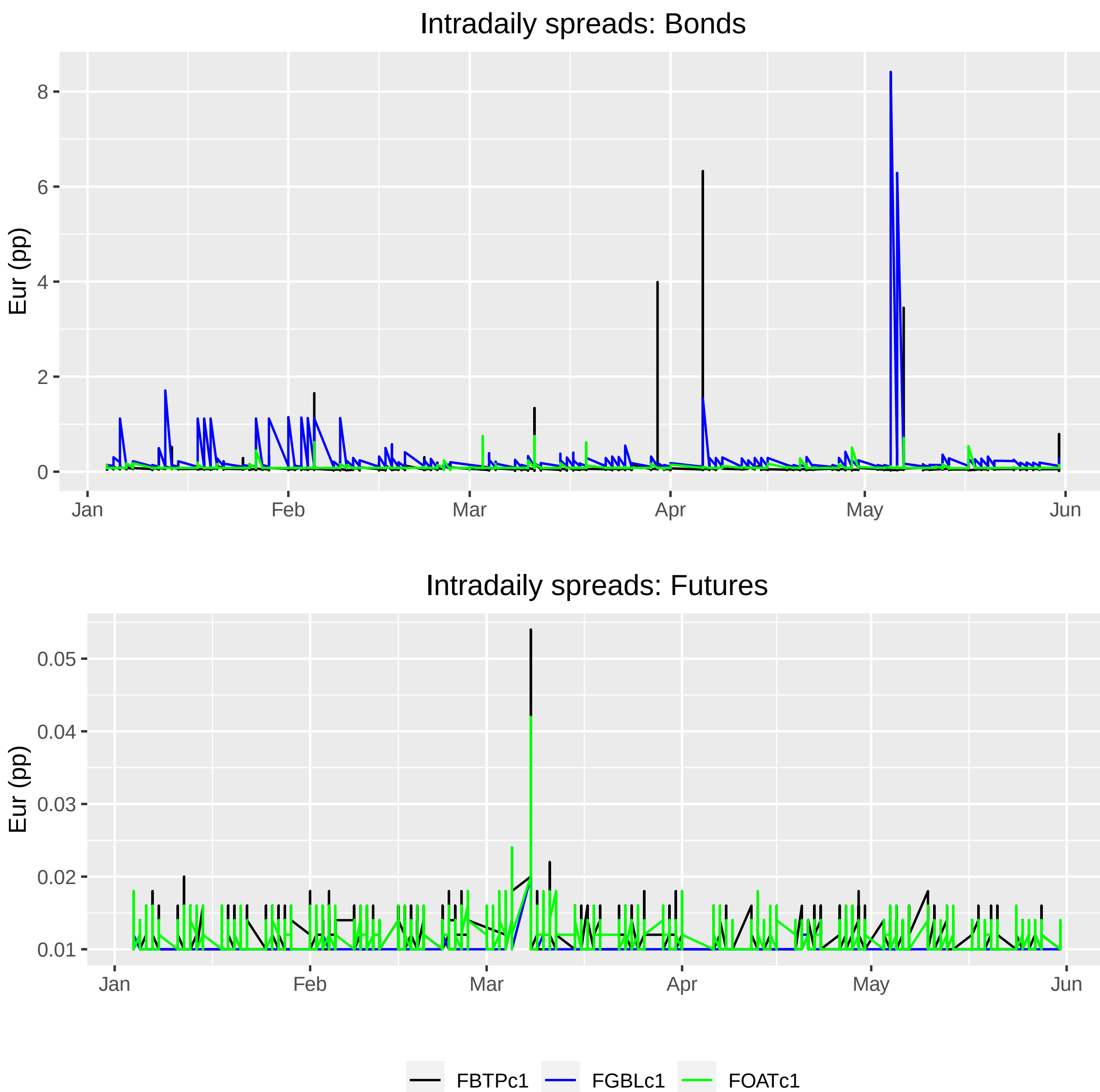
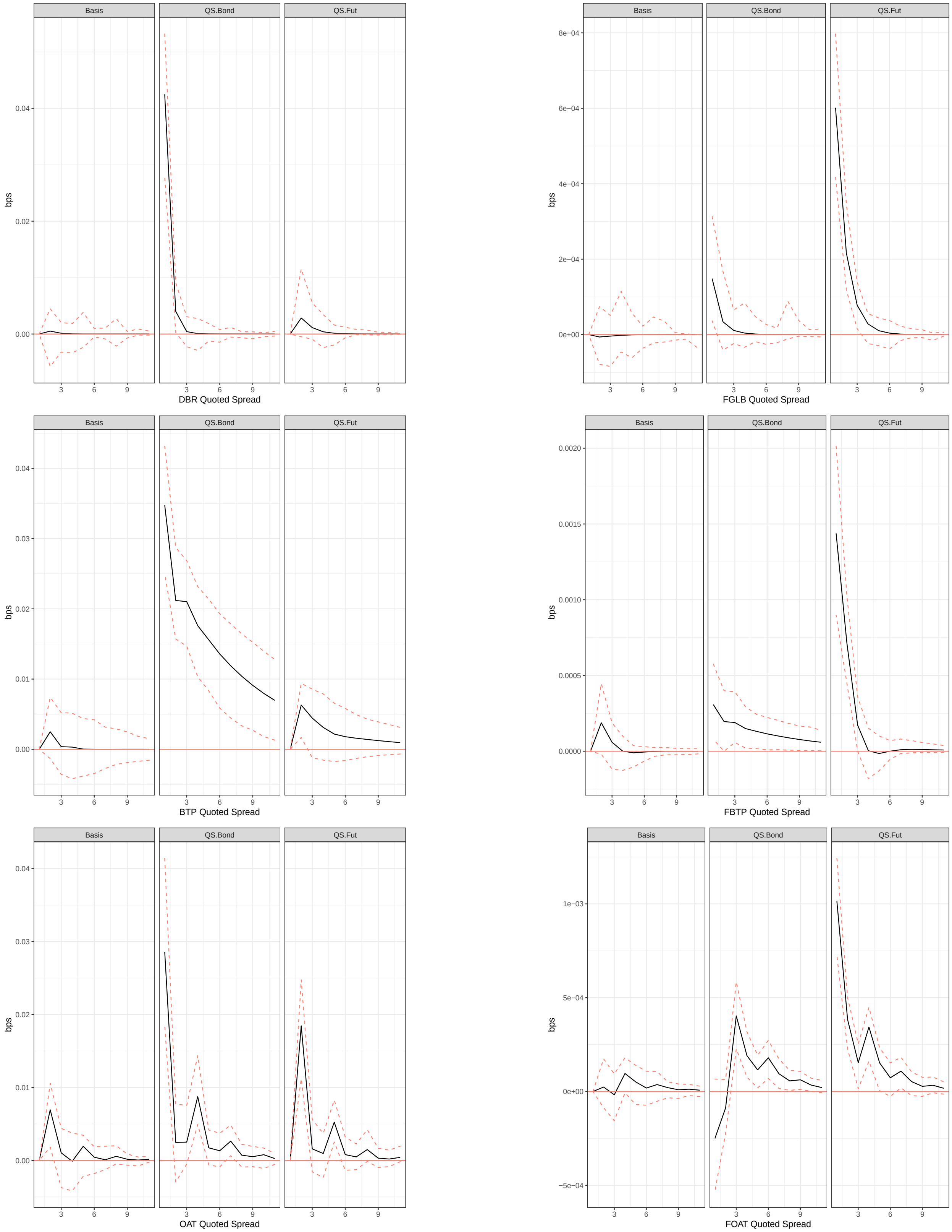
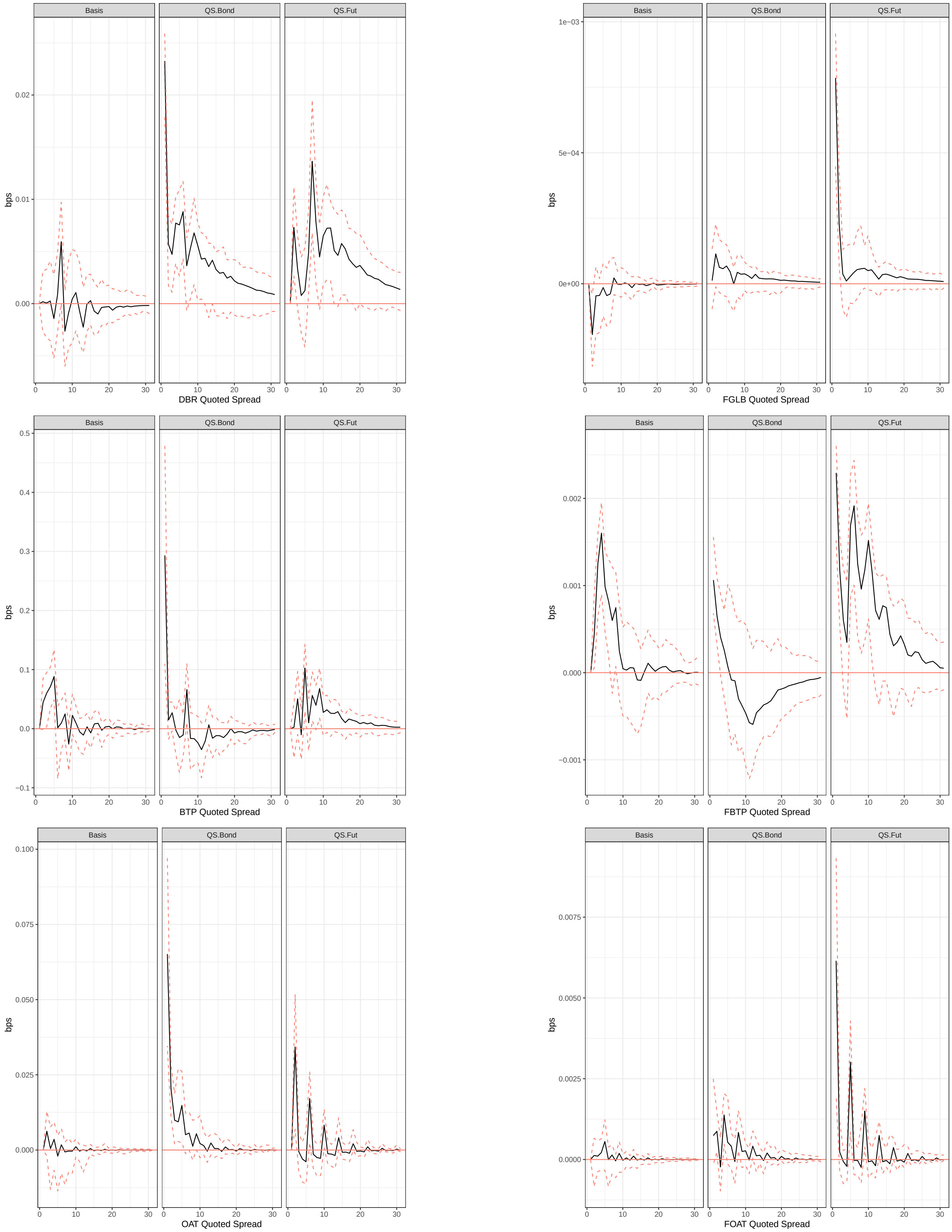


FIGURE 9: **Bid-Ask Spreads in 2021**: This figure plots the quoted bid-ask spread of futures and bonds measured in percentage points of Euro at the five minutes resolution. The top panel reports values for CTD bonds and the bottom panel for futures contracts. Black, blue, and green lines indicate Italian, German, and French contracts, respectively. The data are obtained from the MTS and EUREX markets and the sample spans 01 January 2020 to 01 June 2021.



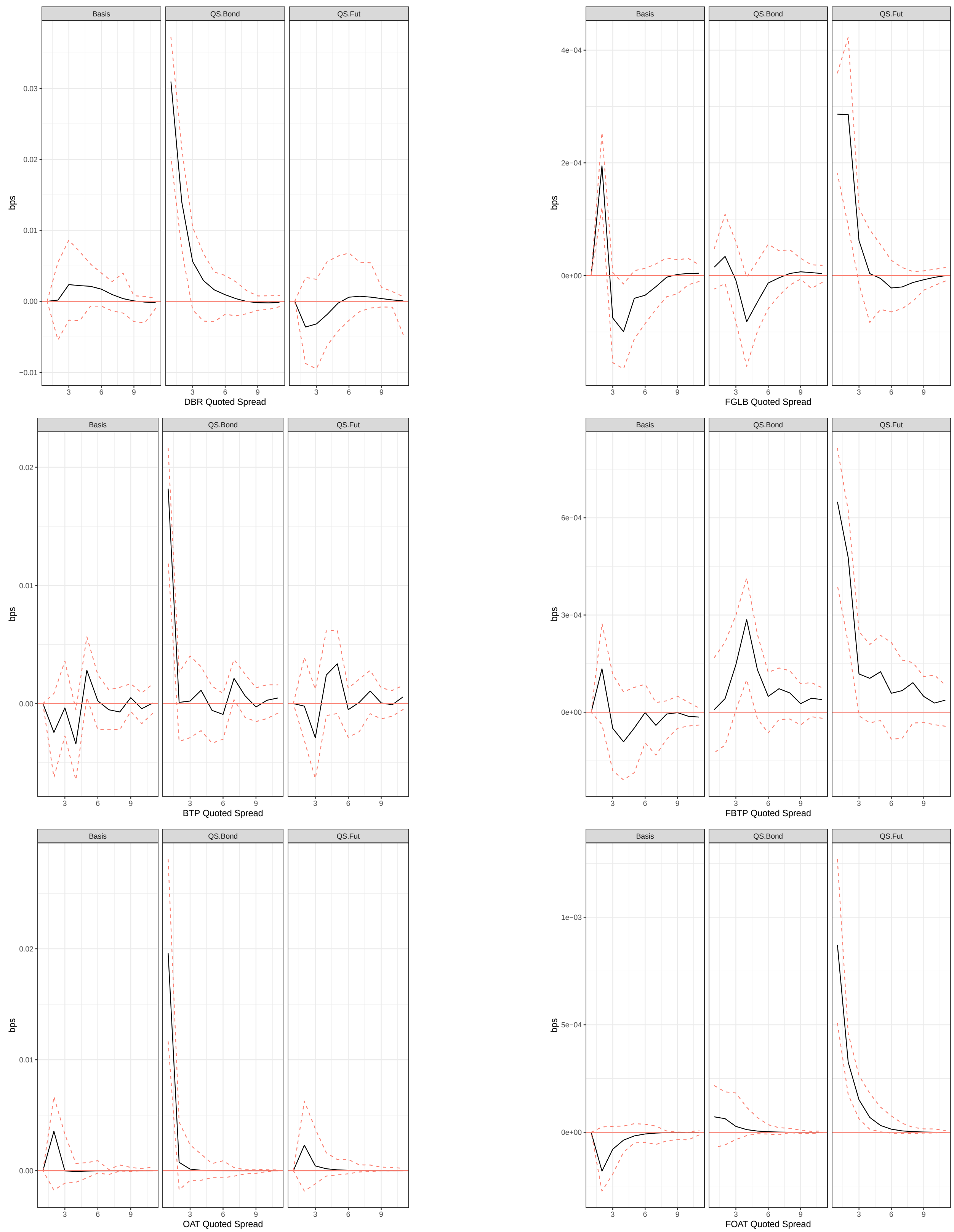
CTD Cash Instrument **Futures Contract**

FIGURE 10: Impulse Response Functions on 2019 data at the daily resolution



CTD Cash Instrument **Futures Contract**

FIGURE 11: Impulse Response Functions on 2020 data at the daily resolution



CTD Cash Instrument **Futures Contract**

FIGURE 12 Impulse Response Functions on 2021 data at the daily resolution

TABLE 1: **Cheapest to Deliver Bonds and Futures Conversion Factors**

The table reports French, German, and Italian cheapest to deliver (CTD) bonds and future conversion factors (CF) for each delivery date. The data are obtained from the MTS and EUREX markets. Repo rates STOXX® GC Pooling EUR ON Index from Bloomberg.

	Germany		Italy		France	
Delivery date	CTD Bond	Futures CF	CTD Bond	Futures CF	CTD Bond	Futures CF
10/03/2019	DE0001102440	0.62789425	IT0004889033	0.91655773	FR0011317783	0.78579514
10/06/2019	DE0001102440	0.62789425	IT0004889033	0.91814920	FR0013286192	0.64422305
10/09/2019	DE0001102457	0.61125077	IT0004889033	0.91990607	FR0013286192	0.65184790
10/12/2019	DE0001102457	0.61955180	IT0004889033	0.92154686	FR0013341682	0.64414093
10/03/2020	DE0001102465	0.61106977	IT0005340929	0.79011084	FR0013341682	0.65168066
10/06/2020	DE0001102465	0,61945988	IT0005340929	0,79011084	FR0013407236	0.62728852
10/09/2020	DE0001102473	0,59436034	IT0005365165	0,79650370	FR0013407236	0.63531243
10/12/2020	DE0001102473	0,59436034	IT0005365165	0,79650370	FR0011883966	0.75273030
10/03/2021	DE0001102499	0.59407576	IT0005024234	0.83380919	FR0011883966	0.75765622
10/06/2021	DE0001102499	0.59407576	IT0005024234	0.83380919	FR0011883966	0.76279356

TABLE 2: **Summary Statistics**

The table reports moments of midprices and quoted spreads for French, German, and Italian bonds and futures at the daily and intradaily frequency. Intraday data are sampled at the 5 minutes resolution. Data from the MTS and EUREX markets spanning 01 January 2019 to 31 December 2019 for the 2019 sample, 01 January 2020 to 09 September 2020 for the 2020 sample, and 01 January 2021 to 01 June 2021 for the 2021 sample.

Annex I – 2019

Panel A: Futures

		Price			Quoted Spread		
		Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
Germany	Daily	170.05	170.90	4.35	0.01	0.01	0.00
	Intradaily	169.70	170.33	4.45	0.01	0.01	0.00
Italy	Daily	135.92	135.69	6.91	0.01	0.01	0.00
	Intradaily	135.06	131.50	6.80	0.01	0.01	0.00
France	Daily	163.35	164.31	5.81	0.01	0.01	0.00
	Intradaily	163.08	164.21	5.93	0.01	0.01	0.00

Panel B: Bonds

		Price			Quoted Spread		
Germany	Daily	105.97	105.76	1.55	0.09	0.08	0.04
	Intradaily	105.84	105.63	1.57	0.10	0.08	0.53
Italy	Daily	124.63	122.11	6.86	0.13	0.11	0.06
	Intradaily	123.74	120.34	6.65	0.13	0.11	0.12
France	Daily	109.74	108.15	5.27	0.09	0.09	0.03
	Intradaily	109.91	108.14	5.42	0.09	0.09	0.14

Annex II – 2020

Panel A: Futures

		Price			Quoted Spread		
		Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
Germany	Daily	174.26	174.28	2.22	0.01	0.01	0.00
	Intradaily	174.50	174.68	2.22	0.01	0.01	0.00
Italy	Daily	143.26	143.35	3.88	0.01	0.01	0.01
	Intradaily	143.92	144.06	3.78	0.01	0.01	0.01
France	Daily	167.70	167.91	1.73	0.01	0.01	0.01
	Intradaily	167.70	167.89	1.79	0.01	0.01	0.02

Panel B: Bonds

		Price			Quoted Spread		
Germany	Daily	106.04	105.87	1.41	0.12	0.12	0.04
	Intradaily	105.82	105.41	1.30	0.12	0.12	0.06
Italy	Daily	114.51	114.93	3.00	0.17	0.11	0.35
	Intradaily	115.05	115.82	2.97	0.17	0.09	0.85
France	Daily	113.42	107.33	10.07	0.13	0.12	0.08
	Intradaily	113.60	107.45	10.09	0.13	0.12	0.38

Annex III – 2021

Panel A: Futures

		Price			Quoted Spread		
		Mean	Median	Std. Dev.	Mean	Median	Std. Dev.
Germany	Daily	173.04	171.86	3.00	0.01	0.01	0.00
	Intradaily	173.21	171.93	3.02	0.01	0.01	0.00
Italy	Daily	149.44	149.60	2.13	0.01	0.01	0.00
	Intradaily	149.58	149.77	2.12	0.01	0.01	0.00
France	Daily	163.00	162.27	2.89	0.01	0.01	0.00
	Intradaily	163.09	162.32	2.91	0.01	0.01	0.00

Panel B: Bonds

		Price			Quoted Spread		
Germany	Daily	103.73	103.48	1.15	0.14	0.13	0.03
	Intradaily	103.79	103.52	1.15	0.14	0.12	0.14
Italy	Daily	125.39	125.75	1.64	0.06	0.05	0.02
	Intradaily	125.49	125.92	1.63	0.06	0.05	0.10
France	Daily	122.38	123.78	4.26	0.08	0.08	0.02
	Intradaily	122.52	123.88	4.22	0.09	0.08	0.05

TABLE 3: **Cointegration Analysis - Rank Tests**

The table reports rank tests for cointegration analysis between futures and cheapest to deliver underlying cash instruments outlined in Equation 1, by country. Panel A, B, and C report the results on the 2019, 2020, and 2021 subsamples, respectively. High frequency data are obtained from the MTS and EUREX markets.

Panel A: 2019

	H_0	H_1	Trace Test (Five-minute)	Trace Test (Daily)	5% Value (Five-minute)
Germany	Rank = 0	Rank > 0	875.84	82.64	19.96
	Rank ≤ 1	Rank > 1	5.85	3.49	9.24
Italy	Rank = 0	Rank > 0	284.87	13.79	19.96
	Rank ≤ 1	Rank > 1	15.69	1.07	9.24
France	Rank = 0	Rank > 0	860.22	58.50	19.96
	Rank ≤ 1	Rank > 1	9.29	5.46	9.24

Panel B: 2020

	H_0	H_1	Trace Test (Five-minute)	Trace Test (Daily)	5% Value (Five-minute)
Germany	Rank = 0	Rank > 0	572.54	57.82	19.96
	Rank ≤ 1	Rank > 1	6.78	5.94	9.24
Italy	Rank = 0	Rank > 0	328.46	17.40	19.96
	Rank ≤ 1	Rank > 1	5.21	5.56	9.24
France	Rank = 0	Rank > 0	462.04	19.77	19.96
	Rank ≤ 1	Rank > 1	12.22	1.40	9.24

Panel C: 2021

	H_0	H_1	Trace Test (Five-minute)	Trace Test (Daily)	5% Value (Five-minute)
Germany	Rank = 0	Rank > 0	134.34	33.54	19.96
	Rank ≤ 1	Rank > 1	4.42	4.93	9.24
Italy	Rank = 0	Rank > 0	87.59	5.56	19.96
	Rank ≤ 1	Rank > 1	2.66	2.68	9.24
France	Rank = 0	Rank > 0	977.12	65.27	19.96
	Rank ≤ 1	Rank > 1	2.24	4.20	9.24

TABLE 4: **Cointegration Relations**

The table reports cointegration analysis between futures and cheapest to deliver underlying cash instruments outlined in Equation 1, by country. Panel A, B, and C estimate the cointegration vector on the 2019, 2020, and 2021 subsamples, respectively. High frequency data are obtained from the MTS and EUREX markets.

Panel A: 2019

		Five-minute		Daily	
		The β Vector	The α Vector	The β Vector	The α Vector
Germany	Futures Price	-0.99033	0.185423	-0.989158	1.263521
	Bond Price	1	0.055977	1	0.618947
	Constant	-1.15061		-1.264139	
Italy	Futures Price	-1.01188	0.15774	-1.00455	0.52729
	Bond Price	1	0.12414	1	0.41717
	Constant	0.82658		-0.05656	
France	Futures Price	-1.00973	0.39770	-1.00733	2.26601
	Bond Price	1	0.28187	1	1.82561
	Constant	0.86223		0.59773	

Panel B: 2020

		Five-minute		Daily	
		The β Vector	The α Vector	The β Vector	The α Vector
Germany	Futures Price	-1.0006	0.27279	-1.0094	0.27041
	Bond Price	1	0.10417	1	-0.36444
	Constant	-0.03653		0.9009	
Italy	Futures Price	-0.96597	0.04747	-0.95923	-0.45227
	Bond Price	1	-0.00356	1	-0.61057
	Constant	-4.30455		-5.07629	
France	Futures Price	-1.01262	-0.01244	-1.01420	-0.01496
	Bond Price	1	-0.07128	1	-0.20871
	Constant	1.20089		1.37853	

Panel C: 2021

		Five-minute		Daily	
		The β Vector	The α Vector	The β Vector	The α Vector
Germany	Futures Price	-1.00424	0.02461	-1.00739	0.45416
	Bond Price	1	-0.00016	1	-0.06061
	Constant	0.38099		0.71449	
Italy	Futures Price	-1.04071	0.01377	-1.15685	0.15520
	Bond Price	1	0.00043	1	0.13811
	Constant	4.58599		18.9941	
France	Futures Price	-1.00366	0.36083	-1.00810	0.63079
	Bond Price	1	0.19685	1	0.26577
	Constant	0.03880		0.65365	

TABLE 5: **Cointegration - Short Term Adjustment Coefficients**

The table reports short term adjustment coefficient in the cointegration model between futures and cheapest to deliver underlying cash instruments outlined in Equation 1 end estimated at the five-minute frequency separately by country. Panel A, B, and C report the results on the 2019, 2020, and 2021 subsamples, respectively. High frequency data are obtained from the MTS and EUREX markets.

Panel A: 2019

	Equation	Lagged ΔVariable	Significant Lags	Of Which Positive
Germany	Futures Price	Futures Price	5 of 5	0 of 5
		Bond Price	3 of 5	0 of 3
	Bond Price	Futures Price	5 of 5	0 of 5
		Bond Price	5 of 5	1 of 5
Italy	Futures Price	Futures Price	1 of 5	0 of 1
		Bond Price	4 of 5	0 of 4
	Bond Price	Futures Price	1 of 5	0 of 1
		Bond Price	4 of 5	0 of 4
France	Futures Price	Futures Price	2 of 5	0 of 2
		Bond Price	4 of 5	0 of 4
	Bond Price	Futures Price	0 of 5	0 of 0
		Bond Price	5 of 5	5 of 5

Panel B: 2020

	Equation	Lagged ΔVariable	Significant Lags	Of Which Positive
Germany	Futures Price	Futures Price	5 of 5	0 of 5
		Bond Price	3 of 5	3 of 3
	Bond Price	Futures Price	5 of 5	0 of 5
		Bond Price	3 of 5	3 of 3
Italy	Futures Price	Futures Price	5 of 5	0 of 5
		Bond Price	3 of 5	3 of 3
	Bond Price	Futures Price	5 of 5	0 of 5
		Bond Price	3 of 5	3 of 3
France	Futures Price	Futures Price	4 of 5	0 of 4
		Bond Price	2 of 5	1 of 2
	Bond Price	Futures Price	3 of 5	0 of 3
		Bond Price	3 of 5	1 of 3

Panel C: 2021

	Equation	Lagged ΔVariable	Significant Lags	Of Which Positive
Germany	Futures Price	Futures Price	2 of 2	1 of 2
		Bond Price	2 of 2	1 of 2
	Bond Price	Futures Price	1 of 2	0 of 1
		Bond Price	1 of 1	1 of 1
Italy	Futures Price	Futures Price	2 of 2	1 of 2
		Bond Price	0 of 2	0 of 0
	Bond Price	Futures Price	2 of 2	1 of 2
		Bond Price	2 of 2	1 of 2
France	Futures Price	Futures Price	1 of 2	0 of 1
		Bond Price	2 of 2	0 of 2
	Bond Price	Futures Price	1 of 2	0 of 1
		Bond Price	1 of 2	0 of 1

TABLE 6: **Liquidity Discovery**

The table reports the estimates of the VAR models described in Equation 2 for daily data and Equation 3 for observations at the five minutes resolution, separately by country and year. High frequency data are obtained from the MTS and EUREX markets.

			2019		**2020**		**2021**	
			Five-minute	Daily	Five-minute	Daily	Five-minute	Daily
Germany	Cash regression	# lags cash	2	0	14	5	6	1
		# lags futures	0	0	0	1	0	0
		# lags basis	0	0	0	1	0	0
		Adj R^2_{cash}	0.07	0.81	0.88	0.96	0.53	0.96
	Futures regression	# lags cash	1	0	2	0	0	2
		# lags futures	8	1	10	1	12	0
		# lags basis	5	0	4	0	2	1
		Adj $R^2_{futures}$	0.99	0.99	0.99	0.99	0.99	0.99
	Basis regression	# lags cash	7	0	0	0	1	0
		# lags futures	8	1	2	1	8	2
		# lags basis	9	1	6	1	7	3
		Adj R^2_{basis}	0.70	0.09	0.60	0.19	0.96	0.80
	Observations		17760	250	9060	164	7912	97
	Lags selected		(max) 15	1	(max) 15	6	(max) 15	3
Italy	Cash regression	# lags cash	14	2	5	2	3	0
		# lags futures	1	1	6	1	1	1
		# lags basis	6	0	7	1	2	0
		Adj R^2_{cash}	0.32	0.94	0.02	0.44	0.02	0.92
	Futures regression	# lags cash	1	1	9	2	3	1
		# lags futures	15	2	15	5	15	3
		# lags basis	1	0	10	2	3	1
		Adj $R^2_{futures}$	0.33	0.99	0.26	0.97	0.34	0.99
	Basis regression	# lags cash	11	1	10	2	7	1
		# lags futures	4	1	6	1	6	1
		# lags basis	5	0	7	3	4	1
		Adj R^2_{basis}	0.23	0.09	0.07	0.26	0.08	0.64
	Observations		17836	249	9050	164	7612	97
	Lags selected		(max) 15	2	(max) 15	6	(max) 15	3
France	Cash regression	# lags cash	13	1	3	2	9	0
		# lags futures	0	2	2	1	0	1
		# lags basis	0	1	4	0	1	1
		Adj R^2_{cash}	0.47	0.91	0.26	0.82	0.91	0.95
	Futures regression	# lags cash	1	1	3	2	2	0
		# lags futures	13	1	15	1	11	2
		# lags basis	1	0	5	0	1	0
		Adj $R^2_{futures}$	0.98	0.99	0.39	0.82	0.98	0.99
	Basis regression	# lags cash	0	0	1	1	0	0
		# lags futures	1	0	2	1	8	0
		# lags basis	8	1	8	2	13	3
		Adj R^2_{basis}	0.68	0.02	0.79	0.11	0.58	0.33
	Observations		19527	251	19923	255	16361	212
	Lags selected		14	2	(max) 15	4	13	3

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