

OUTAGES IN SOVEREIGN BOND MARKETS

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The views expressed in this paper do not necessarily reflect those of the ECB, Deutsche Bundesbank, or Eurosystem.

Risk-free yield curve is key for all asset pricing

We know *why* bond yields change: news and flows

see news literature (Fleming and Remolona, 1999; Andersen et al., 2003, 2007; Gürkaynak et al., 2020; Kerssenfischer and Schmeling, 2022)

and flows literature (Brandt and Kavajecz, 2004; Green, 2004; Pasquariello and Vega, 2007; Deuskar and Johnson, 2011; Gabaix and Koijen, 2021)

But *where* does price formation take place?

- on what trading venues? via which financial instruments?
- are these substitutes or complements?
- are there systematically important venues/instruments?

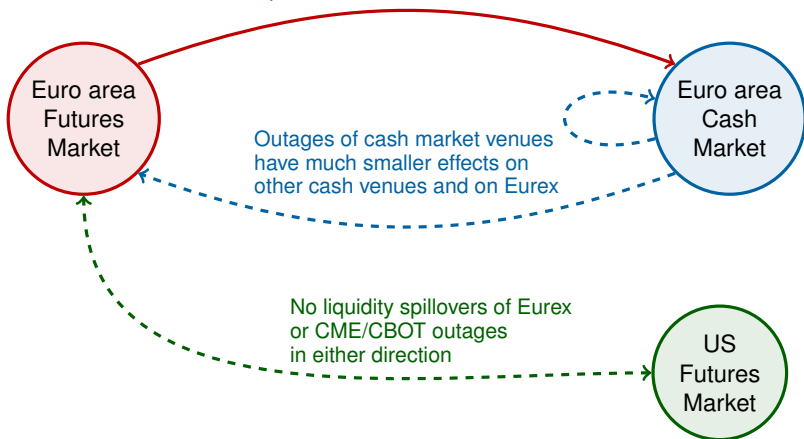
Exploit market outages as natural experiments

- unanticipated and exogenous shocks
- highly informative about how market functions in normal times

Results preview

Outages of Eurex have dramatic effects on cash market:

- trading volumes drop
- market liquidity evaporates
- transaction prices deviate from fundamentals



based on

14 Eurex outages between 2009-2020

Bloomberg outage in 2015, MTS outage in 2019

7 CME/CBOT outages in 2006-2007 and 2019

European Government Bond Market Structure

	Future Market	Cash Market
# assets per country	1-4 futures	~100 bonds
trading venue	Eurex	OTC, Tradeweb, Bloomberg, MTS, ..., or via broker
trading protocol	central limit order book (CLOB)	voice/chat, RFQ, CLOB
transparency	full pre- and post-trade transparency	firm quotes only on MTS, no consolidated tape, MiFID II
our data	full intraday transaction & order book data	see next slide

⇒ cash market is comparatively **fragmented, opaque and heterogeneous** ...

- .. **across countries**: OTC dominates for German, MTS for Italian bonds
- .. **across investor segments**: dealer-to-dealer vs. dealer-to-client

Cash market data

- focus on plain-vanilla government bonds for DE, FR, IT, ES
 - start with regulatory transaction-level dataset
 - "MiFIR" dataset, collected under MiFID II regulation and predecessor "Bafin" dataset, see [de Roure et al. \(2019\)](#); [Gündüz et al. \(2023\)](#) and [Bundesbank website](#)
 - **caveat**: trades in German bonds over-represented
 - due to reporting obligation of trades by German counterparties and in German securities
- ⇒ **hence**: augment with data sourced directly from trading platforms
MTS, MTS BondVision, TPICAP, and Tradeweb
- besides transaction data, study cash market liquidity
- executable quotes and volumes
from MTS
- indicative quotes
from Bloomberg, Refinitiv and TPICAP

Two Eurex Outages in 2020

what happens when Eurex goes down?



14 April 2020
from 9:25 a.m. to 2:00 p.m.

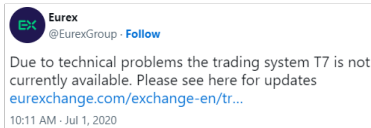
1 July 2020
from 8:49 a.m. to 11:31 a.m.



Eurex
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Due to technical problems, the Eurex T7 system is not available at the moment. We are investigating and will keep you informed

10:32 AM · Apr 14, 2020



Eurex
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Due to technical problems the trading system T7 is not currently available. Please see here for updates eurexchange.com/exchange-en/tr...

10:11 AM · Jul 1, 2020

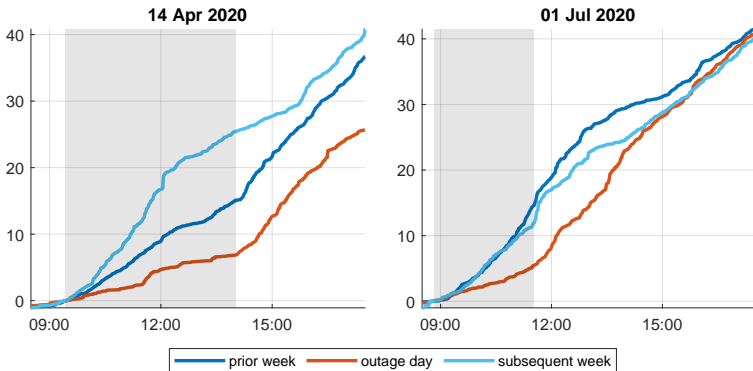
Deutsche Börse: "The disruption in the T7 system in April and today's failure had the same origin. They were due to faulty third-party software that is part of the trading system. [...] External causes can be ruled out." (see [Bloomberg article](#))

How do these outages affect government bonds on the cash market?

Look at

- 1 Trading volumes
- 2 Liquidity
 - Executable Quotes and Volumes
 - Indicative Quotes
- 3 Pricing

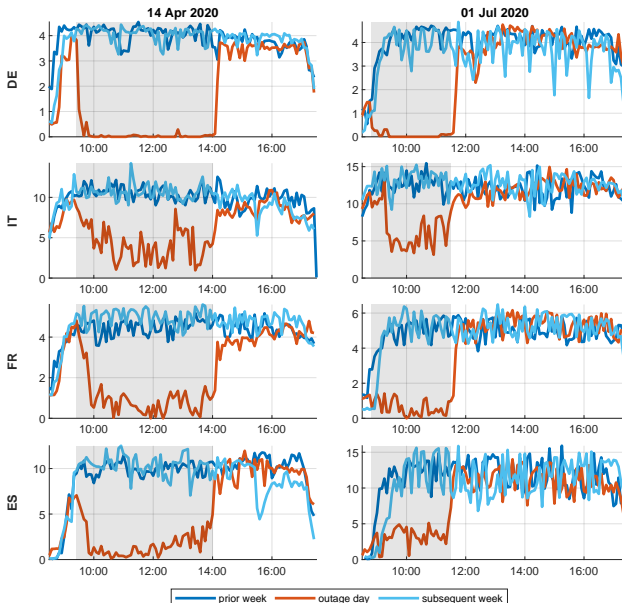
(1) Trading activity in cash EGBs drops ...



Cumulative trading volume on the cash market in all German, French, Italian and Spanish sovereign bonds (in billions of Euro, normalized to zero at the intraday time of the outage).

- **similar** decline in DE/FR/IT/ES bonds, **stronger** decline in long-term bonds ($> 2.5y$ to maturity), see [country/maturity-bucket regression results](#)
- **stronger** decline in on-the-run bonds, see [bond-level regression results](#)

(2a) Executable quotes evaporate



MTS is the major EGB cash trading venue with a CLOB, i.e. firm quotes.

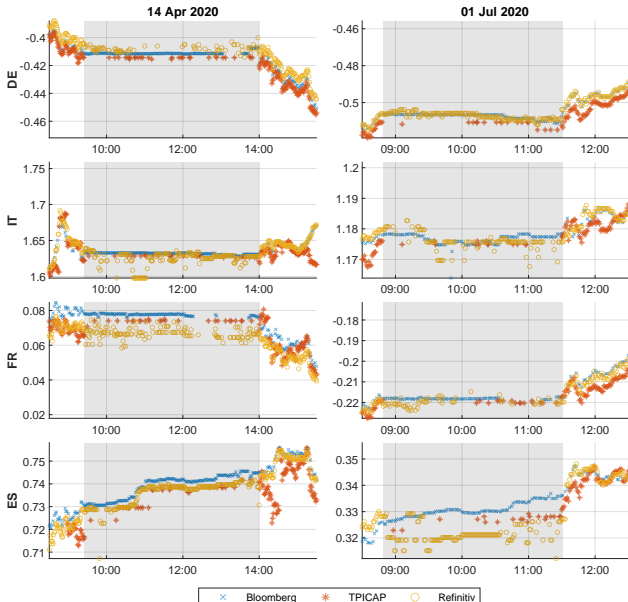
Look at total quoted volume (in billion Euro) of all bonds, across all three levels and both sides of the order book, at 5-minute snapshots.

Compare **outage day** with **previous** and **subsequent** week.

Liquidity most 'robust' for Italian bonds and short-term bonds

bid-ask spreads widen, see paper

(2b) Indicative quotes become stale



bid yield on 10-year government bonds from three data providers

Bloomberg terminal and TPICAP (interdealer broker) data refer to CTD bond

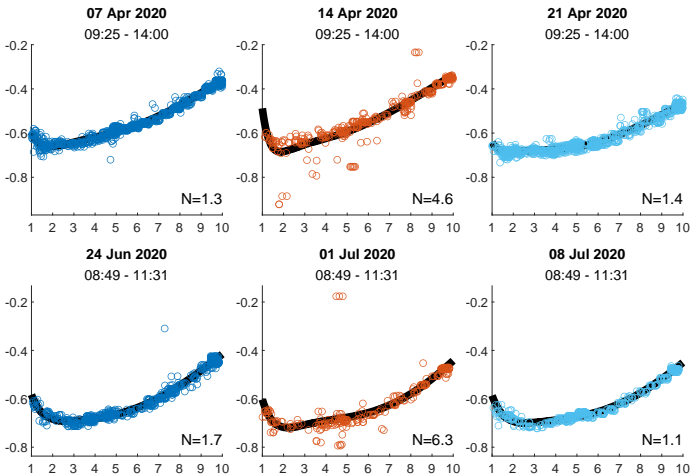
Refinitiv (Eikon) refers to OTR bond, hence apply level adjustment

quotes become stale during Eurex outage

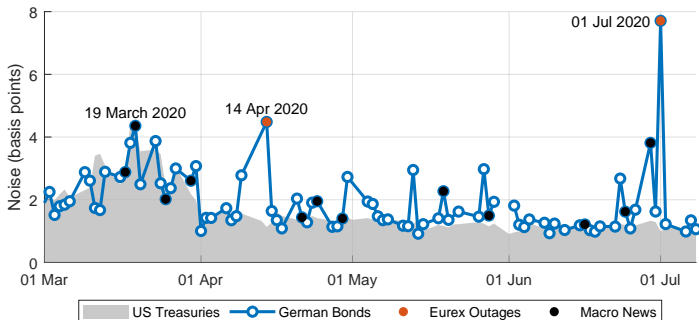
number of quote updates drops, [see Appendix](#)

(3) Pricing errors for cash bonds spike without bond futures

- compare actual yields (derived from transaction prices) with fitted curve
- focus on 1y-10y German bonds: risk-free benchmark curve
- compare **outage windows** with **previous/subsequent** week



(3) Pricing errors are economically large



- repeat previous exercise for all trading days between 1 March and 8 July 2020
- compute root mean squared pricing error: [Hu et al. \(2013\)](#)'s noise measure
- **Eurex outage caused huge pricing errors in German yields**
recall: peak of Covid-19 market turmoil ~19 March (ECB announced PEPP the night before)
- **German yield curve noise remarkably similar to US Treasuries**
despite more noisy sample (intraday vs. end-of-day prices)

(3) Pricing error analysis

which bonds/trades are mispriced?

- usually: errors ↑ for small trades in short-term, OTR and non-CTD bonds
- during outage: errors ↑ for small trades in short-term, non-CTD bonds

see regression results

who commits pricing errors? banks vs hedge funds vs ..

where do pricing errors occur? OTC vs exchange vs ..

⇒ current to-do: exploit non-anonymous Mifir data

Previous Eurex outages provide robustness checks (see paper)

10 other system-wide outages confirm our results

two outages in 2020 not unprecedented, ten other outages since 2008

- trading activity on cash market dropped each time
- as did liquidity on MTS
- larger effects for long-term bonds

2 partial outages highlight role of Bund futures

twice, Eurex went down except for 5y and 10y German bond futures compared to system-wide outage, these partial outages have

- smaller overall effects on MTS liquidity
 - particularly for 5-10y bonds
- Bund futures as pricing benchmark for all EGBs

Cash venue outages

what happens when cash trading platforms go down?



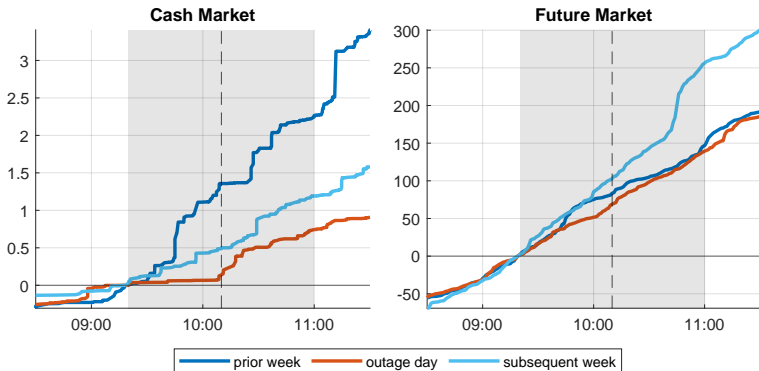
Bloomberg outage on 17 April 2015

- Bloomberg down at 9:20 a.m. CET, [see e.g. BBC News article](#), first Bloomberg terminals back online at 10:10 a.m., [see Yahoo article](#), fully recovered by roughly 11:00 a.m.
- Bloomberg one of the main EGB trading platforms, particularly at the time of the outage

(suspected) MTS outage on 26 July 2019

- no reported outages on MTS, but on 26 July 2019 ...
- ... no quotes and no transactions from 12:30 till 13:20 [see Appendix](#)

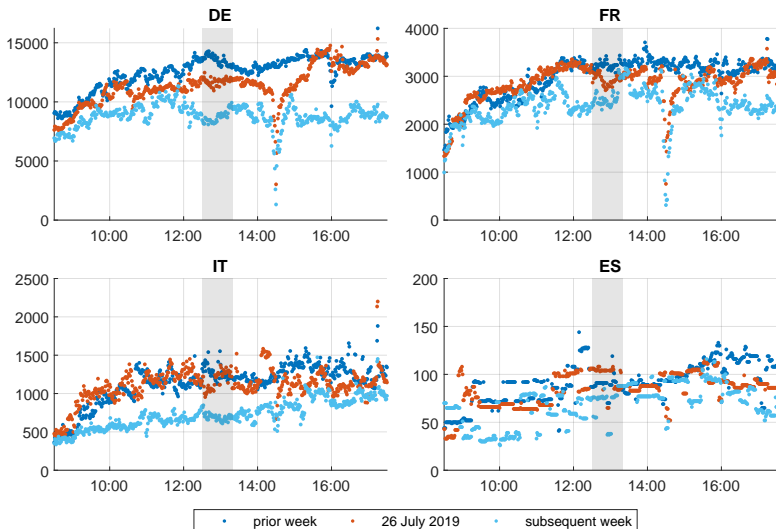
Bloomberg outage affects trading on cash but not futures market



Trading Volumes during Bloomberg Outage. This figure shows the cumulative trading volume of German, French, Italian, and Spanish government bonds (left panel; in billion Euro; from the regulatory 'Bafin' transaction-level dataset) and bond futures (right panel; in thousands of contracts), normalized to zero at the intraday time of the outage. Red lines refer to the outage day, dark and light blue lines refer to the previous and subsequent week. The grey areas mark the approximate outage times of Bloomberg. The dashed vertical line refers to 10:10 CET, when the first Bloomberg terminals were reportedly back online.

- virtually no trades on cash market prior to 10:10 a.m.
- little effect on bond futures (slightly fewer trades in DE and FR, more trades in IT, see paper)
- small impact on MTS platform [see Appendix](#)

Suspected MTS outage has no effect on Eurex



Order Book Depth of 10-year Bond Futures on Eurex. This figure shows the total number of contracts quoted at the first fifteen levels on both sides of the order book, at minutely snapshots. Red dots refer to the potential MTS outage day (26 July 2019), dark and light blue dots refer to the previous and subsequent week.

US/EA Spillovers

do outages spill over between
Eurex and CME/CBOT?

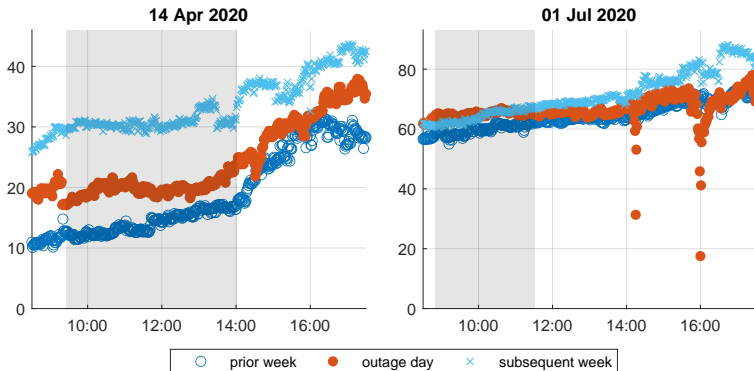


use Eurex outages to study EA→US

use CME/CBOT outages to study US→EA

- on 26 February 2019, the Chicago Mercantile Exchange (CME) was down from 7:39-10:45 p.m. US Eastern Time ([see FT article](#))
- between 2006-2007, six outages on the Chicago Board of Trade (CBOT), predecessor of CME ([Harding and Ma, 2010](#))

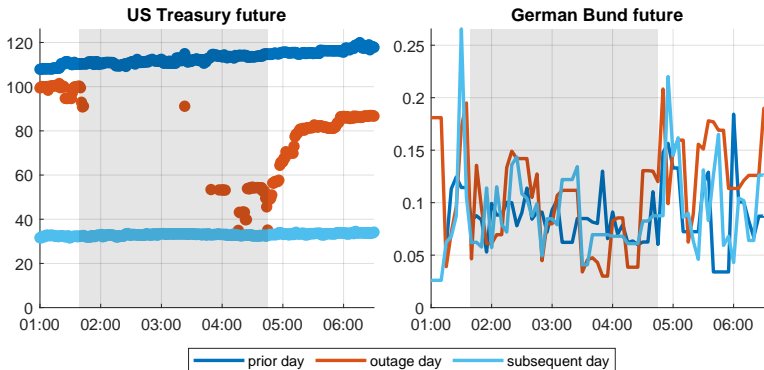
Eurex outage has little impact on US Treasury futures



Order Book Depth of US Treasury Futures during Eurex outages. This figure shows the number of quoted contracts (in thousands) at the first 15 levels of both sides of the order book for 10-year Treasury futures. The grey area refers to the outage period on Eurex.

- small temporary drop in liquidity only for 1st outage
- maybe no surprise, but what about the other way around?
We know US → EA price spillovers very strong (see [Boehm and Kroner, 2023](#))

CME outage has little impact on Bund futures



Order Book Depth of US and German Bond Futures during the CME Outage. This figure shows the order book depth of 10-year US Treasury and German Bund futures (both in thousands of contracts). Treasury liquidity covers the first 15 order book levels while Bund liquidity only covers the first level (data comes from Bloomberg, since our Eurex order book data starts in April 2019). Red lines refer to the outage day, dark and light blue lines refer to the previous and subsequent day. The grey areas mark the approximate outage times of CME. Timestamps are in CET.

- no discernible decrease in Bund future liquidity
- due to timing of outage (very early morning)? No, see [previous CBOT outages](#)
- Is Bund future more independent than previously thought?

Conclusion

Bond futures are key for EGB market functioning

Without futures,

- trading volumes on cash market drop
- market liquidity evaporates
- transaction prices deviate from fundamentals

No symmetric outage effect between cash venues \longleftrightarrow future market

price discovery and liquidity provision more of a one-way street
from futures \rightarrow cash market

No liquidity spillovers from US Treasury futures \longleftrightarrow Euro area bond futures

liquidity provision occurs 'domestically',
not conditionally on foreign risk-free yield curve

Contribution to literature

Competing theories of liquidity spillovers

- × theories of *cross-market arbitrage* imply symmetric outage effects: future ↔ cash (see [Gromb and Vayanos, 2010](#); [Harding and Ma, 2010](#))
- [Cespa and Foucault \(2014\)](#) propose model based on *cross-asset learning*
- key idea: some particularly informative asset prices are used to price and provide liquidity in other assets
- ✓ in our case: bond futures → cash bonds

Dominant vs. satellite markets

- Usual focus is on stocks traded on multiple exchanges (cross-listed instruments)
- [Hasbrouck \(1995\)](#); [Guillaumie et al. \(2020\)](#): price discovery occurs on primary exchange
- ✓ in our case: futures exchange = dominant market, spot market platforms = satellite markets

Implications for policy makers: costs and benefits of centralisation

Future Market

- trading and clearing fully centralized on Eurex
- handful of highly liquid securities
- ⇒ central role for price discovery
- × **outage of Eurex a systemic risk**

Cash Market

- fragmented across competing trading venues, often without central clearing
- many quite illiquid bond issues
- ⇒ minor role for price discovery
- ✓ **robust to outage of individual venues**

recent reform proposals:

- central clearing and all-to-all trading on cash market?
see e.g. [Duffie \(2023\)](#) and [U.S. Securities and Exchange Commission \(2022\)](#)
- condense sovereign debt into handful of perpetual bonds?
see e.g. [John Cochrane \(2015\)](#) for the US and [Garriott et al. \(2020\)](#) for Canada

Motivation
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Market Structure and Data
○○

Eurex Outages
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Other Outages
○○○○○○○

Conclusion
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References

Appendix
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Thanks for your attention

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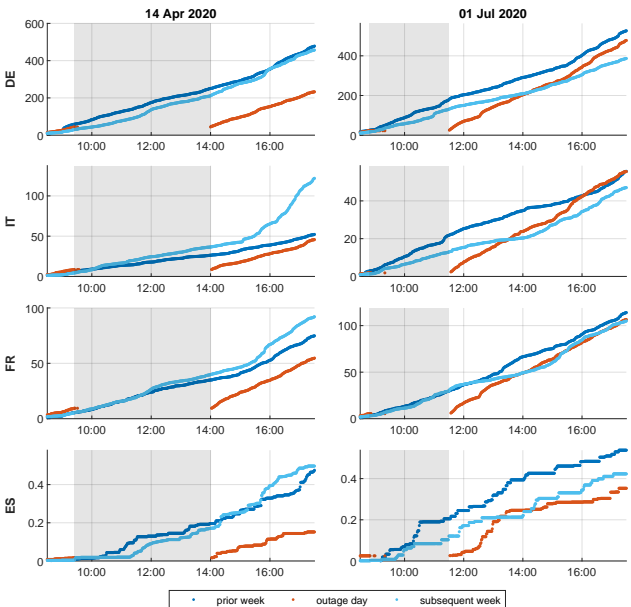
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Trading indeed stopped for all bond futures during 2020 Eurex outages



Cumulative trading volume in 10-year bond futures.

Number of traded front-end contracts in thousand.

Compare **outage day** with **previous** and **subsequent** week.

• prior week • outage day • subsequent week

Eurex outage effect on cash volumes across countries/maturities [jump back](#)

estimate $\log(1 + Volume_{cmt}) = \alpha + \gamma \times D_t + \beta \times FE + \epsilon_t$

for bonds of country c in maturity-bucket m and 30-minute interval t , $D_t = 1$ during outage

	(1) Aggregate	(2) Maturities	(3) Countries
Outage	-2.66***	-0.96**	-2.45***
2.5-5.5y		-1.04**	
5.5-10.5y		-0.01	
>10.5y		-1.32**	
Outage × 2.5-5.5y		-2.12***	
Outage × 5.5-10.5y		-2.14**	
Outage × >10.5y		-2.55**	
ES			-3.22***
FR			-3.35***
IT			-0.85**
Outage × ES			0.09
Outage × FR			-0.54
Outage × IT			-0.41
FE Day	✓	✓	✓
FE Time	✓	✓	✓
FE Country	✓	✓	
FE Maturity Bucket	✓		✓
Observations	1536	1536	1536
Adjusted R^2	0.333	0.340	0.332

Each column refers to a different regression, $Volume_{cmt}$ is the total trading volume in bonds of country c and maturity bucket m in the 30-minute time interval t . All explanatory variables are dummies: for time periods during Eurex outages, for different maturity buckets (bonds with less than 2.5 years to maturity serve as the baseline) or for different countries (Germany serves as the baseline). SEs are clustered at the daily level. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectively. The aggregate effect implies a $\exp(-2.66) - 1 \approx 93\%$ drop in trading volumes on average across maturity-buckets and countries.

Eurex outage effect on cash volumes at bond level

[jump back](#)

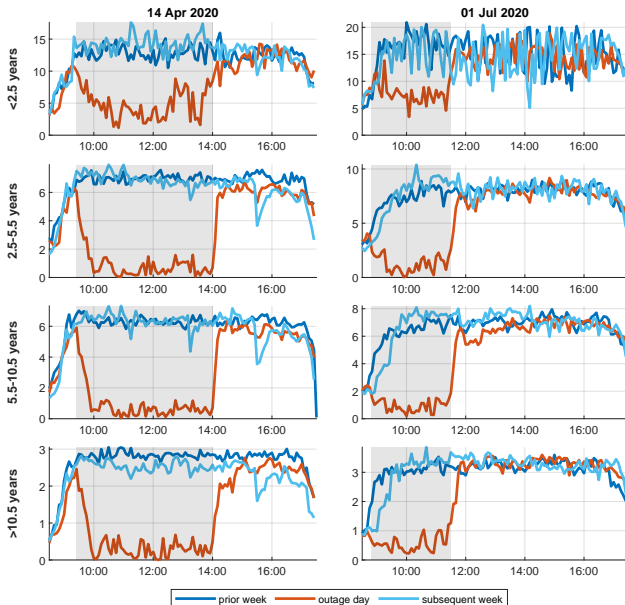
estimate $\log(1 + Volume_{it}) = \alpha + \gamma \times D_t \times BondCharacteristics + \beta \times FE + \epsilon_{it}$
 for individual bonds i and 60-minute intervals t , $D_t = 1$ during outage

	(1)	(2)
Outage	-3.04***	-2.99***
CTD		2.24***
OTR		2.12***
Zero Coupon		-2.15***
log(Years to Maturity)		0.98***
log(Years since Issuance)		-1.14***
Outage × CTD		-0.87
Outage × OTR		-2.71***
Outage × Zero Coupon		0.69*
Outage × log(Years to Maturity)		-0.26
Outage × log(Years since Issuance)		0.21
FE Day	✓	✓
FE Time	✓	✓
FE ISIN	✓	
FE Country		✓
Observations	13986	13986
Adjusted R^2	0.329	0.257

Each column refers to a different regression, $Volume_{it}$ is the transaction volume in a given bond i in 1-hour intervals. To avoid compositional effects, we study a fixed set of 259 bonds throughout. Trading volumes drop $\exp(-3.04) - 1 = 95\%$ on average across bonds.

- usually, CTD and OTR bonds traded more frequently
- during the Eurex outage, trading in OTR bonds drops disproportionately

Eurex outage effect on MTS liquidity across maturities

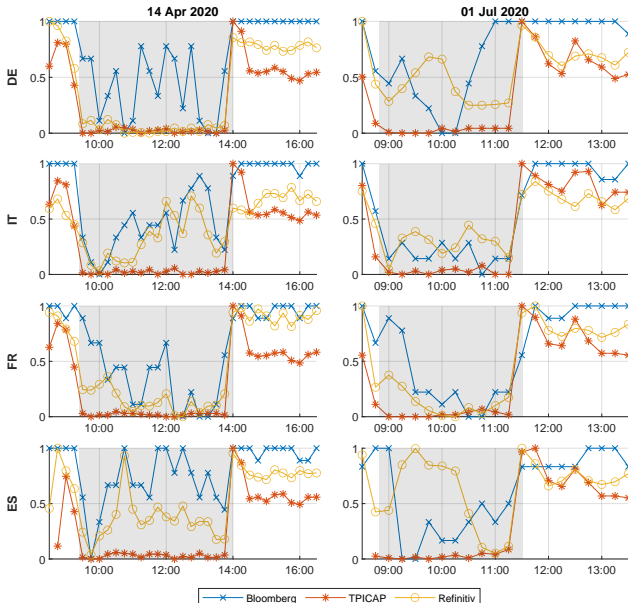
[jump back](#)

Instead of countries, compare MTS order book depth across maturity buckets:

- <2.5 years
- 2.5 - 5.5 years
- 5.5 - 10.5 years
- >10.5 years

short-term bonds most 'robust'

Eurex outage effect on indicative quote updates

[jump back](#)


number of new bid quotes per 15min window, normalized to 0-1 range per data provider

Bloomberg: approximate 'new quotes' as price changes in 10y CTD bond

TPICAP: new quotes in 10y CTD bond

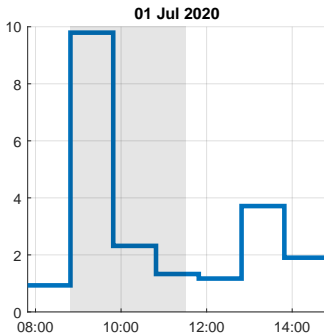
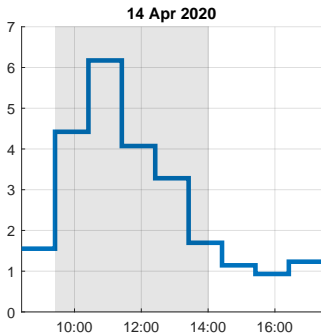
Refinitiv (Eikon): real-time feed updates for 10y OTR bond from "Tick History"

clear drop in number of quote updates

Cash market pricing errors clearly linked to Eurex outage times

concern: pricing errors higher on outage days, for reasons other than Eurex?

- compute root mean squared pricing error as before
- but for one-hour intraday windows throughout the two outage days



answer: no

- ⇒ noise \uparrow at outage start and \downarrow at outage end
- intraday data is key, spike would not be visible in end-of-day prices

Cash market pricing errors during Eurex outage

jump back

estimate $abs(PE_{it}) = \alpha + \gamma \times D_t \times Characteristics + \beta \times FE + \epsilon_{it}$ at transaction level

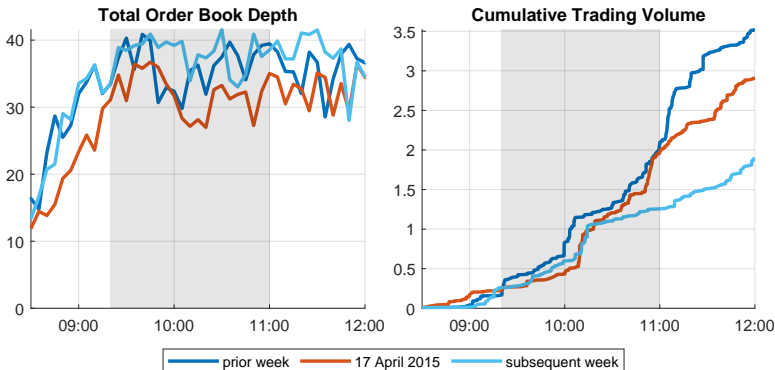
	(1)	(2)	(3)
Outage	1.23***	1.13***	-3.14***
log(Volume)		-0.14	-0.03**
CTD		-0.39*	-0.26**
OTR		0.19	0.21**
Zero Coupon		0.04	0.09
Years since Issuance		0.06*	0.05
Years to Maturity		-0.08	-0.03
Outage × log(Volume)			-0.69***
Outage × CTD			-0.90*
Outage × OTR			-0.59
Outage × Zero Coupon			-0.04
Outage × Years since Issuance			0.02
Outage × Years to Maturity			-0.14**
FE Minute	✓	✓	✓
FE ISIN	✓		
Observations	3362	3362	3362
Adjusted R^2	0.113	0.123	0.220

The dependent variable is the absolute pricing error, i.e. the difference between the observed and fitted yield based on [Svensson \(1994\)](#). The sample spans all trades in one to ten year German bonds during the Eurex outages and during the same intraday window in the previous and subsequent week. Standard errors are clustered at the daily level. All regression include time-of-day fixed effects at the 15-minute frequency. *, **, *** indicate statistical significance at the 10%, 5% and 1% level, respectively.

usually: errors ↑ for small trades in short-term, OTR and non-CTD bonds

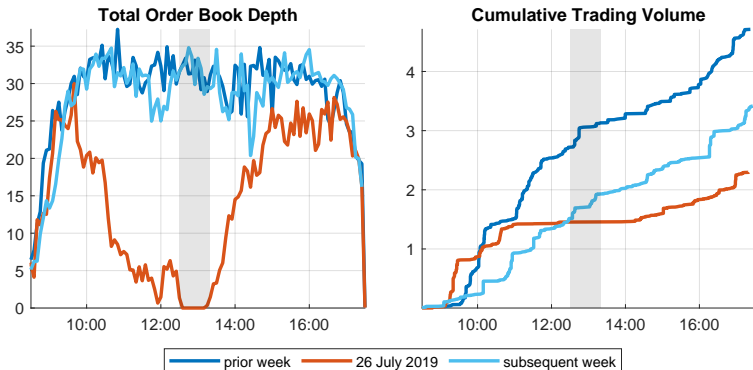
during Eurex outage: errors ↑ for small trades in short-term, non-CTD bonds

Blomberg outage has little impact on MTS

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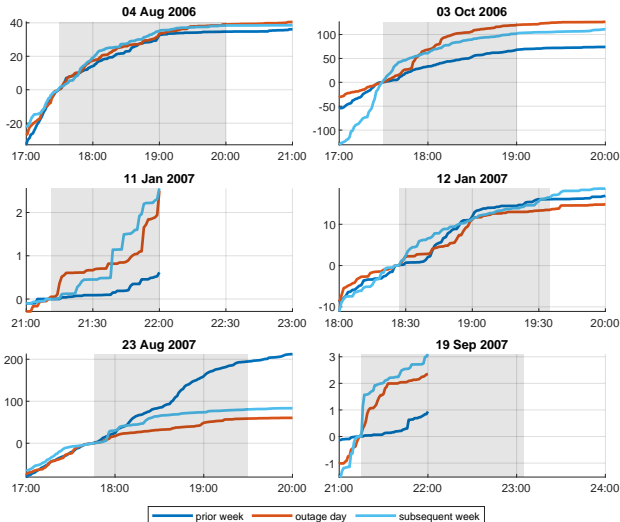
MTS Order Book Depth and Trading Volumes during Bloomberg Outage. The left panel shows the total order book depth at 5-minute snapshots (in billion Euro), the right panel shows the cumulative trading volume on MTS (in billion Euro). Both panels cover all of German, French, Italian and Spanish sovereign bonds on MTS. Red lines refer to the outage day, dark and light blue lines refer to the previous and subsequent week. The grey areas mark the approximate outage times of Bloomberg. The dashed vertical line refers to 9:10 London time, when the first Bloomberg terminals were reportedly back online.

Suspected MTS outage on 26 July 2019

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The left panel shows the total quoted volume on MTS (in billion Euro), across all German, French, Italian and Spanish sovereign bonds and all market segments, in 5-minute intervals. The right panel shows the total cumulated trading volume on MTS (in billion Euro). Red lines refer to 27 July 2019 (the potential MTS outage day), dark and light blue lines refer to the previous and subsequent week.

Previous CBOT outages also had little impact on Bund futures

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No order book data for 2006-2007; look at cumulative trading volume of 10-year German bond futures around CBOT outages (in thousands of contracts, normalized to zero at the intraday time of the outage). Grey areas mark the outage times of CBOT.

No systematic effect

Implications for practitioners: data reliability

When bond future prices become unavailable ...

- ... executable quotes for EGBs vanish
- ... indicative quotes for EGBs become stale
- ... as do quotes on interest rate swaps beyond $\sim 2y$ maturity

Generous interpretation

→ those quotes are tightly linked to bond future prices

Less generous interpretation

→ those quotes contain little inherent information

calculation methods behind quotes not disclosed, e.g. [Bloomberg website](#) describes quotes as "*a real-time composite based on executable and indicative quotes from multiple contributors [...] indicative of available consensus-forming prices, and designed for broad terminal use*"

we show: bond futures prices are vital input

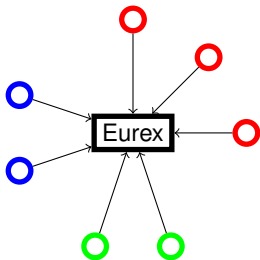
Size of Futures vs Cash Bond Market in Euro Area

Country	Future Volume (billion €)	Cash Volume (billion €)	Ratio Future/Cash
Germany	72,044	7,404	9.7
France	7,745	5,435	1.4
Italy	8,367	7,197	1.2
Spain	21	2,002	.01

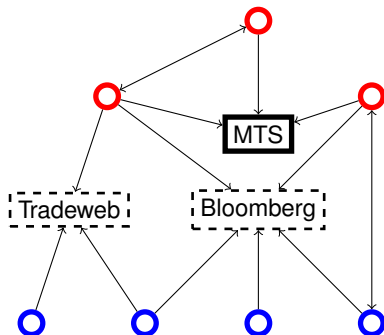
Table: Trading volumes in 2022. The bond future trading volumes correspond to the aggregate volume of all futures of a given country, from [Eurex website](#). The cash market trading volumes are based on the [European Secondary Bond Market Data Report](#) by the International Capital Market Association (ICMA).

Illustrative EGB Market Structure

Futures market



Cash market



- Dealer (large banks)
- Client (e.g. pension funds)
- HFTler

- on-exchange (CLOB)
- ⌚ electronic (RFQ)
- over-the-counter (voice)