Outages in Sovereign Bond Markets

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Motivation

sovereign bonds are at the core of the financial system

- understanding market functioning and price formation is important

but underlying market microstructure is complicated

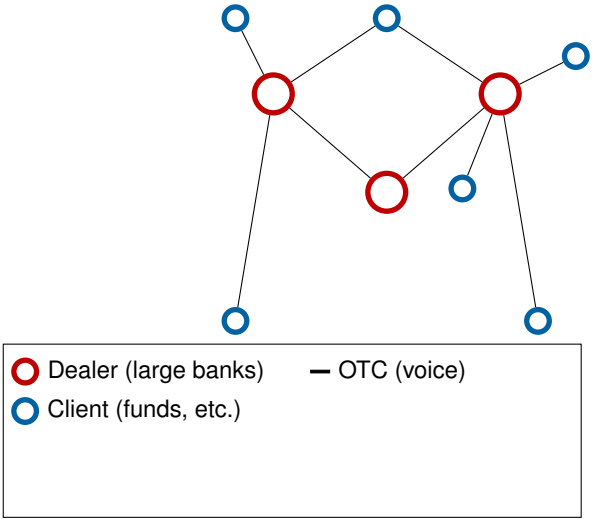
- different **investors** trade different **instruments** on different **markets**
- hard to isolate causal mechanisms

we exploit trading platform outages as natural experiments

- ***who*** drives price discovery?
- ***how*** do intermediaries connect markets?
- ***where*** does liquidity originate?

Illustrative European Government Bond Market Structure

Cash market



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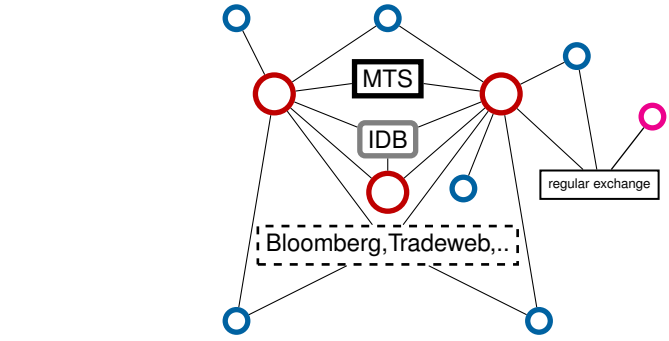
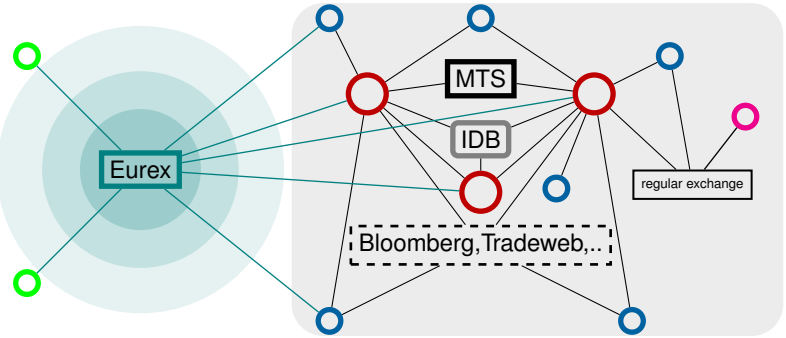


Illustrative European Government Bond Market Structure

Futures market

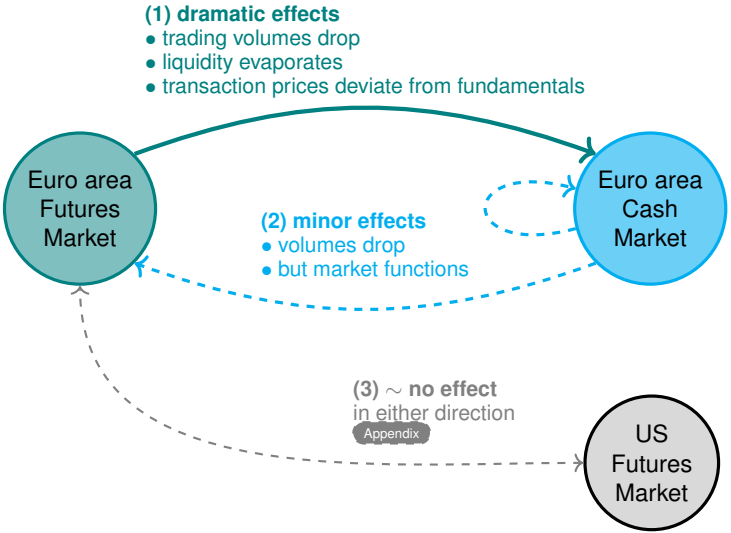
Cash market



Market Structure Summary and Data

	Futures Market	Cash Market
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
# assets per country	max. 4 futures	∼100 bonds
our data		
non-anonymous trades (Mifid II)	EMIR	MiFIR
+ intraday trades		MTS, Bondvision, Tradeweb, TPICAP, BGC, GFI, Aurel
+ intraday quotes	Eurex	MTS, Bloomberg, Refinitiv, TPICAP

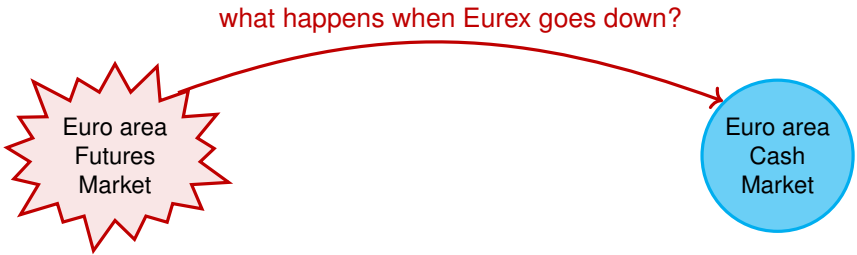
Results preview: macro-level effect of outages



based on

- 14 Eurex outages between 2009-2020
- MTS outage in 2010/2019, Bloomberg 2015, FWB 2015, Brokertec 2019
- 6 CBOT outages in 2006-2007 and CME outage 2019

Futures Market Outages



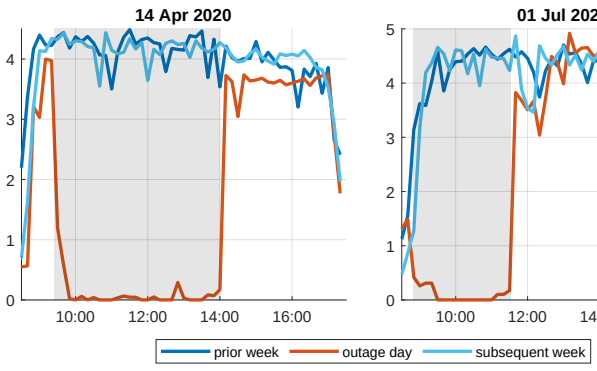
focus on two most recent outages:

- 14 April 2020 for $\sim$ 4.5 hours
- 1 July 2020 for $\sim$ 3 hours

Deutsche Börse: *"the disruption[s] [..] had the same origin. They were due to faulty third-party software"*

12 previous outages between 2009-2018 serve as robustness check

Executable quotes evaporate



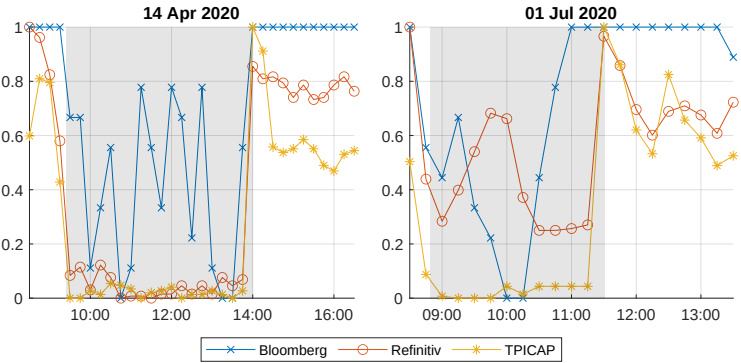
MTS is the dominant D2D venue with a CLOB, look at total quoted volume (in billion Euro) of all Bunds, across all three levels and both sides of the order book, at 10-minute snapshots.

Compare outage day with previous and subsequent week.

Order book volumes evaporate

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

Indicative quotes become stale



Bloomberg & Refinitiv/Eikon: D2C venues
TPICAP: interdealer broker

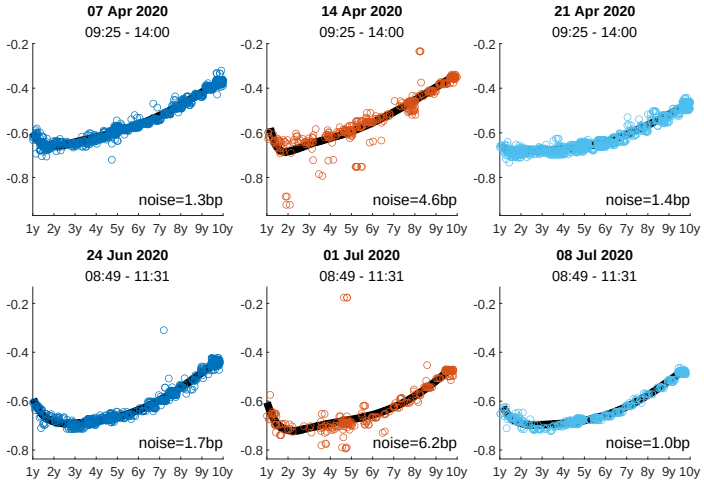
look at number of new bid quotes per 15min window, normalized to 0-1 range per data provider

Compare outage period with just before/after.

clear drop in number of quote updates

results hold for FR/IT/ES
Appendix

Mispricing spikes



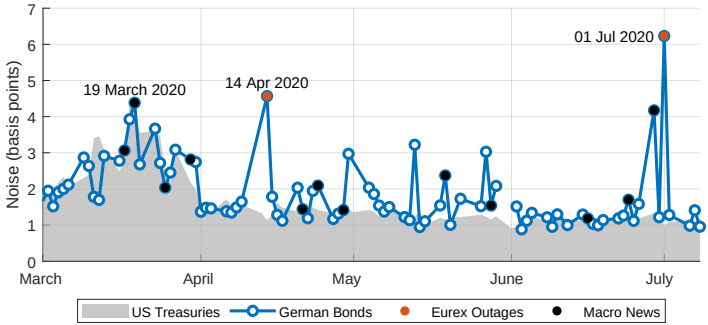
compare actual yields (implied by transaction prices) with fitted curve

focus on 1y-10y German bonds: risk-free Euro benchmark curve

compare outage windows with same window in the previous/subsequent week

many trades at dislocated prices, RMSE (Hu et al. (2013)'s noise measure) increases $\sim$ fivefold

Mispricing is economically large



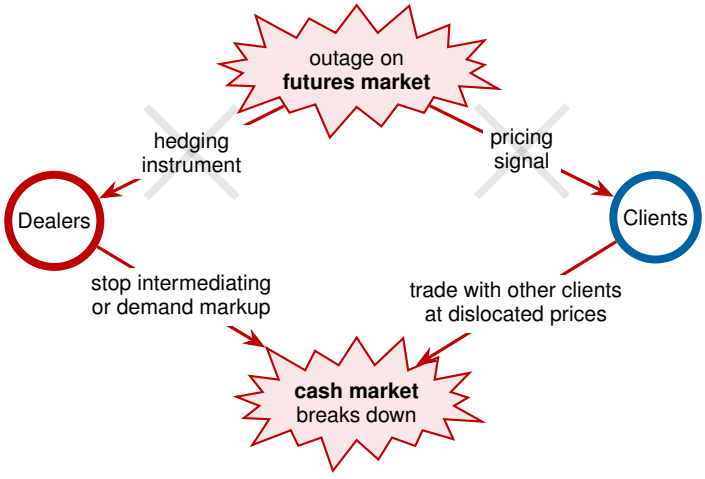
compute daily Bund noise, using same intraday windows as on outage day

outage effect is huge

recall: peak of Covid-19 crisis ∼19 March (ECB announced PEPP the night before)

side note: German yield curve noise remarkably similar to US Treasuries, despite more noisy sample (intraday vs. end-of-day prices)

Micro-level mechanism



Outage effects across investor segments

	(1) Volume	(2) Mispricing
Outage × C2C	-2.04 [1.12]	3.34*** [0.20]
Outage × D2C	-2.69*** [0.32]	0.72*** [0.13]
Outage × D2D	-4.93*** [0.84]	0.35 [0.36]
FE Day	✓	
FE Time	✓	✓
FE Maturity Bucket	✓	
FE ISIN		✓
Observations	1080	3214
Adjusted R^2	0.377	0.164

trading volume drops *most*, mispricing spikes *least* in D2D segment

dealers well-informed & patient

clients relatively uninformed & impatient (unaware of outage?)

Dealer cross-section: Outages as shocks to hedging instruments

sort dealers into 3 groups

- 5 dealers hedging <5% of cash mkt. duration risk via futures: "no hedging" group
- 5 dealers hedging >25% of duration risk: "intense hedging" group
- 21 remaining dealers in "moderate hedging" group

	(1) volume	(2) mispricing	(3) markup	(4) profit
Outage × Dealer not hedging	0.55 [1.02]	0.32 [0.30]	-0.29 [0.61]	-0.50 [4.28]
Outage × Dealer moderately hedging	-2.34** [0.59]	0.81*** [0.13]	0.31** [0.11]	3.30* [1.40]
Outage × Dealer intensely hedging	-5.35** [1.71]	0.32* [0.14]	0.16 [0.35]	1.19 [2.42]
FE Minute	✓	✓	✓	✓
FE ISIN		✓	✓	✓
FE Client Sector		✓	✓	✓
Observations	162	1877	1877	1877
Adjusted R^2	0.364	0.069	0.030	0.032

Sample includes all D2C transactions during the two outage and four control windows. Dependent variables are calculated from the dealer perspective.

- capacity constraints binding for intense hedging group
- moderate hedging group trades if profitable

Client cross-section: Outages as shocks to pricing signals

	(1) mispricing	(2) markup	(3) profit
Outage	-0.70** [0.24]	-2.11*** [0.32]	-6.40 [8.90]
Outage × # Connections	-0.02* [0.01]	0.04*** [0.01]	0.32*** [0.06]
Outage × Relationship w/ Dealer	-1.38* [0.58]	0.50 [0.70]	4.82** [1.72]
Outage × ln(Dealer Centrality)	-0.25*** [0.04]	-0.22 [0.14]	0.14 [0.75]
Outage × Dealer moderately hedging	0.85*** [0.15]	0.14 [0.13]	-3.44 [4.33]
Outage × Dealer intensely hedging	0.88** [0.24]	0.36 [0.31]	-1.61 [5.03]
FE Minute	✓	✓	✓
FE ISIN	✓	✓	✓
FE Sector	✓	✓	✓
Observations	1662	1662	1662
Adjusted R^2	0.124	0.040	0.034

Sample includes all D2C transactions. # Connections refers to the number of different dealers a client has traded with. Dealer Relationship measures the fraction of buying/selling volume of each client-dealer pair as a share of the total volume of each client. Dealer Centrality is the volume-weighted eigenvector centrality of the dealer involved in the transaction.

- better connected (more sophisticated) clients fare better during outages
- the stronger the relationship, the less dealers extract profits from their clients

Cash market outages

what happens when cash market venues go down?

5 outages affecting 4 different venues

- MTS (2x)
- Bloomberg
- Frankfurt stock exchange (FWB)
- Brokertec

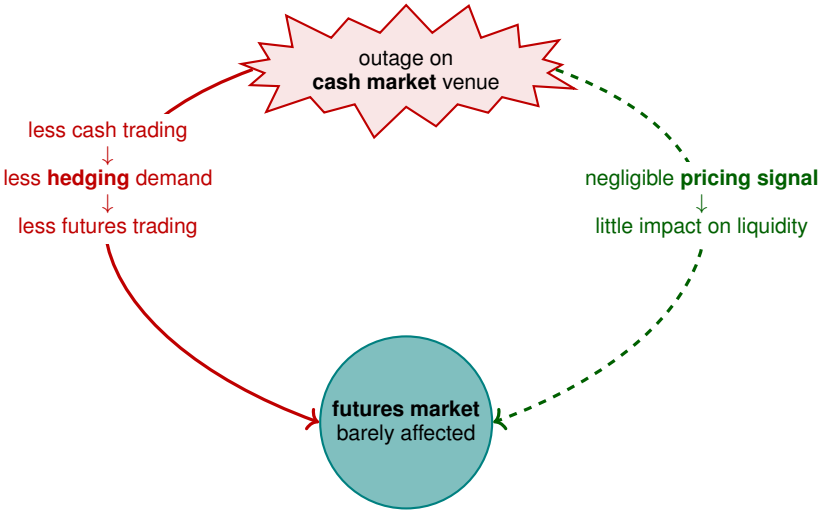
Cash outages reduce trading activity, not market functioning

	MTS 12 Jan 2010 8:00-10:35	Bloomberg 17 Apr 2015 9:20-10:10	FWB 27 May 2015 8:00-11:00	Brokertec 11 Jan 2019 19:43-21:35	MTS 26 Jul 2019 12:30-13:20	Pooled
Cash market						
Volume	-1.33*** [0.11]	-4.45*** [0.13]	-0.43* [0.10]		-2.35* [0.69]	-1.46*** [0.44]
#Trades	-0.17*** [0.00]	-0.38 [0.17]	-0.08 [0.08]		-0.28*** [0.01]	-0.17*** [0.05]
Futures market						
Volume	0.02 [0.03]	-0.25* [0.06]	-0.59 [0.50]	-0.23*** [0.01]	-0.55** [0.12]	-0.31* [0.17]
#Trades	0.03 [0.05]	-0.15** [0.02]	-0.29 [0.26]	-0.16** [0.03]	-0.43* [0.14]	-0.17* [0.09]
Volatility	0.09 [0.10]	-0.02 [0.03]	-0.44 [0.41]	-0.04 [0.02]	-0.11 [0.09]	-0.20 [0.19]
Amihud	0.02** [0.00]	0.03*** [0.00]	0.09 [0.05]	-0.09 [0.15]	0.07 [0.02]	0.05* [0.03]
Roll	0.02 [0.05]	0.08* [0.02]	0.15* [0.04]	-0.13 [0.14]	0.05 [0.02]	0.09** [0.03]

imperfect substitution between cash venues: aggregate activity ↓ during outage on individual venue

futures market barely affected: trading activity ↓ slightly, illiquidity ↑, but effect orders of magnitude smaller than vice versa

Micro-level mechanism



true out-of-sample test from last week...

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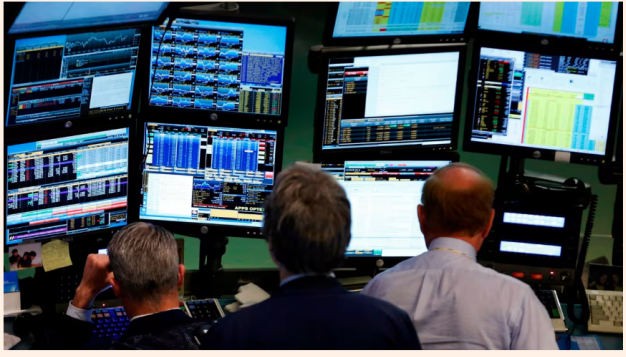
Bloomberg LP + Add to myFT

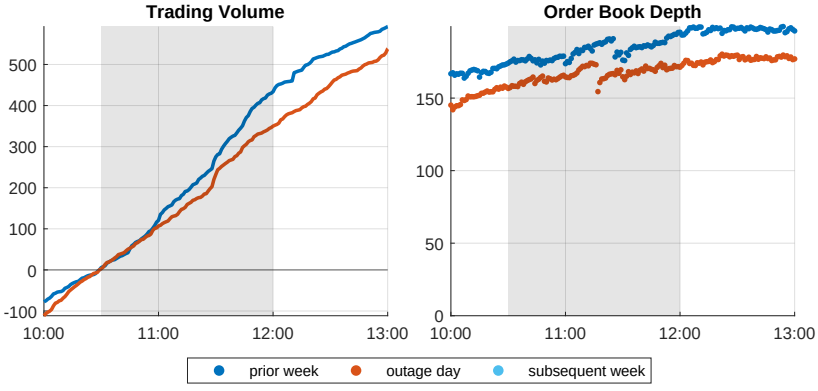
Bloomberg terminal outage hits traders

Disruption to widely used markets data service affects UK and EU debt auctions



Traders complained that the Bloomberg service had been running with significant delays © Brendan McDermid/Reuters

Bloomberg outage on 21 May 2025



look at trading volume and order book depth across all Bund futures on Eurex

(in thousands of contracts)

trading volumes ↓ slightly
∼ no effect on liquidity

Contribution to literature

Competing theories of liquidity provision:

- × cross-market arbitrage
  implies symmetric outage effects: future ↔ cash (Gromb and Vayanos, 2010, 2018; Harding and Ma, 2010)
- ✓ cross-asset learning
  more informative asset price used to price other assets (Admati, 1985; Cespa and Foucault, 2014; Asriyan et al., 2017)

Market structure trade-offs:

- decentralized cash market free-rides on centralized futures market
  (positive benchmark externality, see Duffie et al., 2017)
- centralization brings liquidity, price discovery, ... but also systemic risk

Limits to arbitrage & dealer capacity:

- importance of intermediaries in financial markets
  (Long et al., 1990; Shleifer and Vishny, 1997; Gromb and Vayanos, 2002, ...)
- natural experiment confirming recent US Treasury evidence
  Duffie et al. (2023)

Thanks for your attention

Size of Futures vs Cash Bond Market in Euro Area

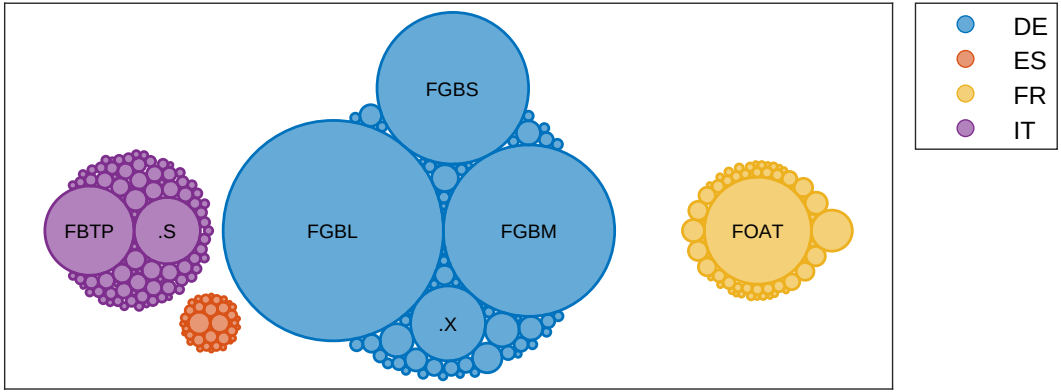
jump back

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

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). All data refers to 2022.

Cash market is "fragmented" across bonds

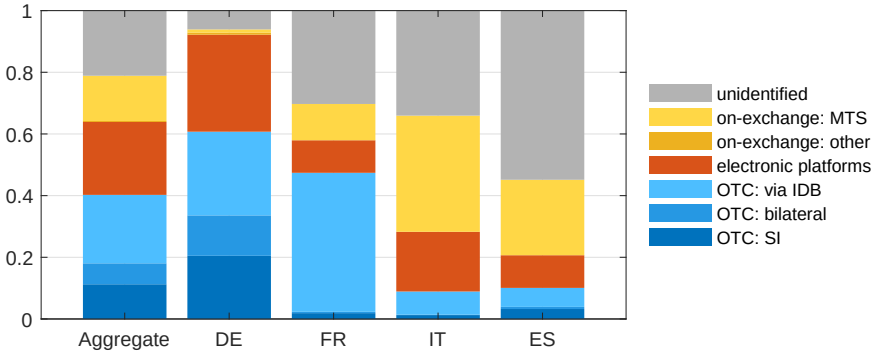
jump back



EGB Trading Volumes at the Instrument-Level. Each circle refers to an individual bond or bond future, with its size proportional to the notional trading volume. Bond futures are labelled, e.g. "FGBL" for the 10-year Bund future. Sample covers only plain-vanilla government bonds. For the cash market, the number of bonds per country and the distribution of trading volumes across those bonds are based on our transaction dataset for a particular day (7 April 2020). The Spanish bond future is not labelled due to its low trading volume (roughly equal to the median volume across Spanish cash bonds). See paper for details.

Cash market is "fragmented" across venues

jump back



market shares of cash trading venue types at aggregate and country-level, based on our transaction dataset for all four non-outage days (i.e. April 7 and 21, June 30 and July 8, 2020); "IDB" refers to interdealer brokers, "SI" refers to systematic internalisers and "other exchanges" refer to regular stock exchanges.

Descriptives: # of Investor Types

	Eurex-Active	Eurex-Inactive	Total
Bank Dealer	29	2	31
Bank Non-Dealer	12	68	80
NBFI	6	39	45
Investment Fund	5	220	225
Hedge Fund	6	61	67
ICPF	1	55	56
NFC	0	20	20
Official	0	16	16
Household	0	1	1
Total	59	482	541

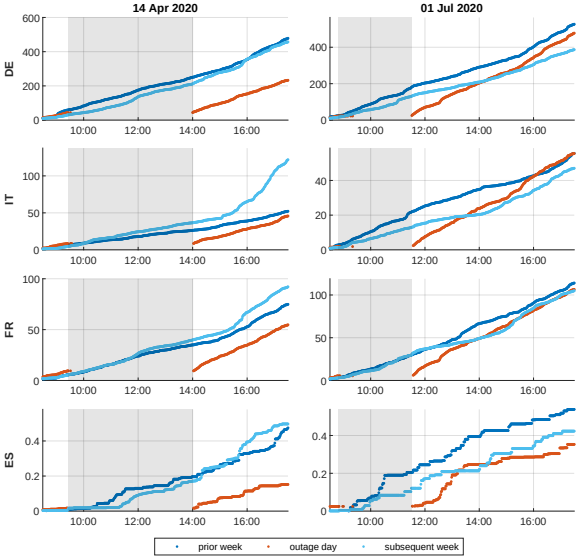
Number of Investors by Type. Data refers to investors with cash Bund trades on six selected days in 2020. Investors are aggregated to group-level. 31 dealers matched to >100 LEIs. The category "households" comprises an unknown number of retail investors, as these are not uniquely identifiable via a LEI.

Descriptives: # of Trades across Investor Types

	No Outage	Outage	Total
Bank Dealer	2595	489	3084
Bank Non-Dealer	539	175	714
NBFI	474	117	591
Investment Fund	489	99	588
Hedge Fund	256	64	320
ICPF	175	19	194
NFC	30	12	42
Official	323	25	348
Household	137	65	202
Total	5018	1065	6083

Number of Cash Transactions by Investor Type. All figures refer to transactions in German sovereign bonds with 1-10 year maturity during the two Eurex outages in 2020 and the four non-outage control windows. With two sides to each trade, the totals sum to roughly twice the number of trades (abstracting from unknown investor types due to anonymous transaction data).

Trading indeed stopped for all bond futures during 2020 Eurex outages

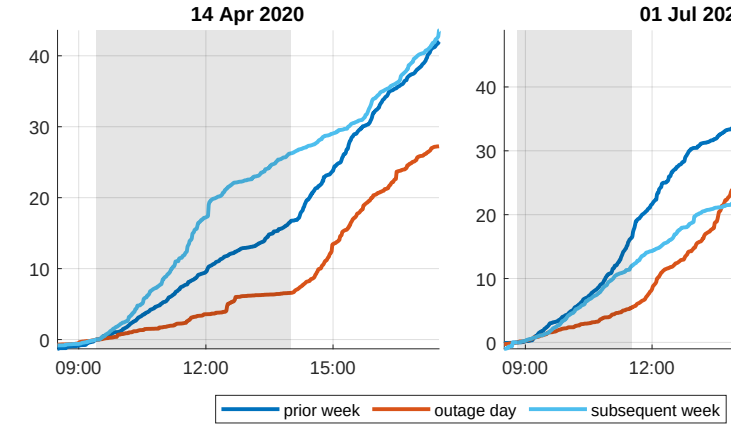


Cumulative trading volume in 10-year bond futures.

Number of traded front-end contracts in thousand.

Compare outage day with previous and subsequent week.

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 next slide

→ **stronger** decline in on-the-run bonds, see bond-level regression results

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) Average	(2) Maturities	(3) Countries
Outage	-3.10***		
Outage × <2.5y		-1.07**	
Outage × 2.5-5.5y		-3.69***	
Outage × 5.5-10.5y		-3.81***	
Outage × >10.5y		-3.83**	
Outage × DE			-2.75***
Outage × FR			-3.36**
Outage × IT			-3.24***
Outage × ES			-3.05**
FE Day	✓	✓	✓
FE Time	✓	✓	✓
FE Country	✓	✓	
FE Maturity Bucket	✓		✓
Observations	1440	1440	1440
Adjusted R^2	0.324	0.335	0.323

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.

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

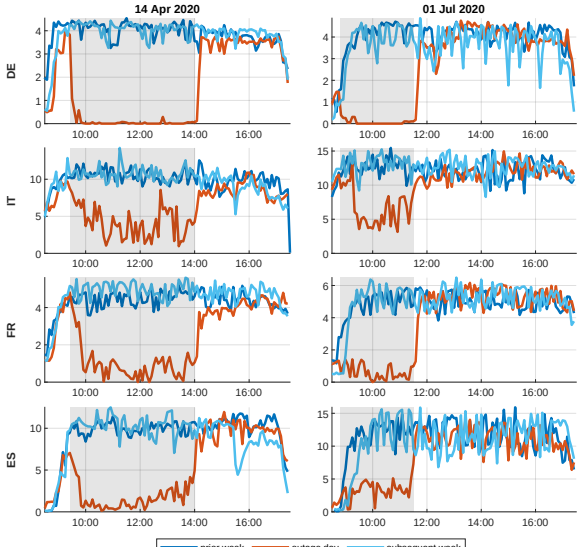
	(1)	(2)
Outage	-3.16**	-3.65**
CTD		2.73***
OTR		1.15**
Zero Coupon		-1.36***
log(Years to Maturity)		0.88***
log(Years since Issuance)		-1.15***
Outage × CTD		-1.30*
Outage × OTR		-1.46**
Outage × Zero Coupon		0.69*
Outage × log(Years to Maturity)		0.06
Outage × log(Years since Issuance)		0.31
FE Day	✓	✓
FE Time	✓	✓
FE ISIN	✓	
FE Country		✓
Observations	10752	10752
Adjusted R^2	0.284	0.231

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.

- 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 countries

jump back



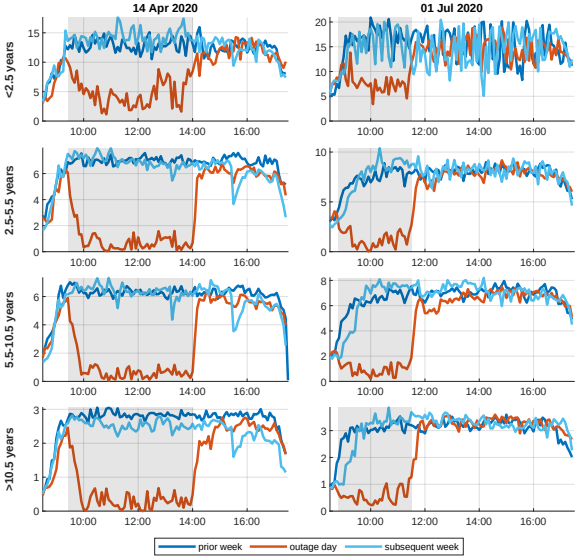
Look at total quoted volume (in billion Euro) of all bonds, across all three levels and both sides of the order book, at 5-minute snapshots.

Compare outage day with previous and subsequent week.

Quoted volumes evaporate, only few remaining quotes (at huge bid-ask spreads, see paper)

Eurex outage effect on MTS liquidity across maturities

jump back



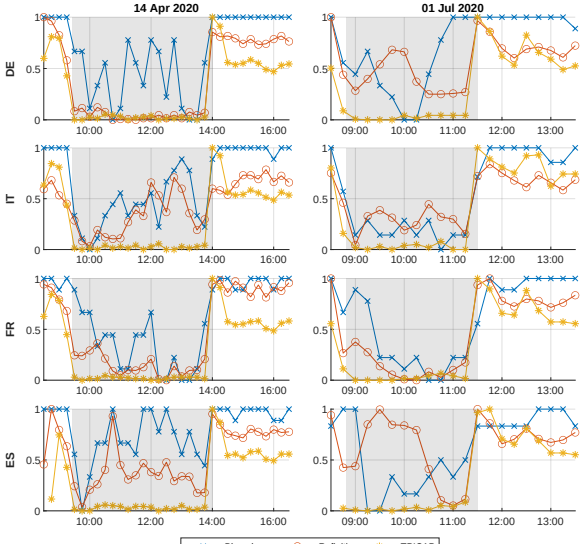
Instead of countries, compare MTS order book depth across maturity buckets

- below 2.5 years
- 2.5 - 5.5 years
- 5.5 - 10.5 years
- above 10.5 years

short-term bonds most ‘robust’

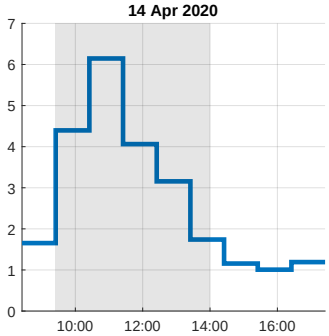
Eurex outage effect on indicative quotes across countries

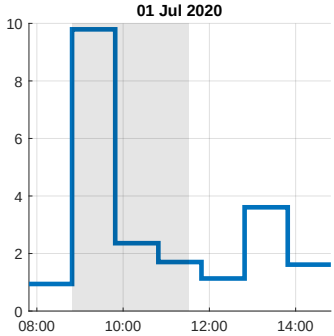
jump back



clear drop in number of quote updates for all countries

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 ↑ at outage start and ↓ at outage end
- → intraday data is key, spike would not be visible in end-of-day prices

Micro-level evidence: trading venues

	(1) Volume	(2) Mispricing
Outage × OTC bilateral	-5.13*** [1.06]	1.97*** [0.40]
Outage × OTC via IDB	-3.26*** [0.66]	0.14 [0.28]
Outage × OTC via SI	-3.98*** [0.42]	0.17 [0.25]
Outage × electronic platforms	-2.95*** [0.35]	0.91*** [0.17]
Outage × MTS	-2.55*** [0.39]	0.00 [.]
Outage × regular exchange	-0.18 [0.63]	4.46*** [0.97]
FE Day	✓	
FE Time	✓	✓
FE Maturity Bucket	✓	
FE ISIN		✓
Observations	2160	3038
Adjusted R^2	0.445	0.166

trading volume drops *most* OTC, *least* on MTS & exchanges

outage akin to "urgency shock" Menkveld et al. (2017)'s

"pecking order hypothesis": investors usually rank low cost low immediacy venues (OTC) first and high cost high immediacy venues (exchanges) last, reverse ordering during urgency shock

unaffected volumes & big mispricing on exchanges points to retail investors

Micro-level evidence: mispricing across investor types

(1) $abs(PE)_i = |y_i - \hat{y}_i|$

(2) $markup_i = y_i - \hat{y}_i$ for buys, reverse for sells

(3) $profit_i = \text{markup}_i \times \text{volume}_i \times \text{maturity}_i$

	(1) mispricing	(2) markup	(3) profit
Outage × Bank Dealer	0.61*** [0.12]	0.26 [0.13]	2.33** [0.63]
Outage × Bank Non-Dealer	1.90*** [0.14]	0.65 [0.50]	-1.37* [0.66]
Outage × NBFI	1.24** [0.38]	0.48** [0.13]	0.95 [0.54]
Outage × Investment Fund	0.44** [0.14]	-0.67*** [0.09]	-2.93 [1.46]
Outage × Hedge Fund	2.62*** [0.31]	2.74*** [0.45]	1.56 [1.81]
Outage × ICPF	0.27 [0.41]	-0.51** [0.15]	-6.19 [3.22]
Outage × NFC	1.78 [1.64]	-1.28 [2.18]	-1.17 [2.56]
Outage × Official	0.20 [0.13]	-0.31 [0.27]	-3.11 [1.92]
Outage × Household	4.29*** [0.69]	-4.04*** [0.34]	-2.46* [1.16]
FE Minute	✓	✓	✓
FE ISIN	✓	✓	✓
Observations	6083	4701	4701
Adjusted R^2	0.165	0.054	-0.008

y_i is actual yield (implied by transaction price), $\hat{y}_i$ is fair yield (from fitted yield curve)

mispricing is widespread

dealer markups ↑, particularly for large trades in long-term bonds: trade profitability ⇑

hedge funds opposite: markups ⇑, but profitability ↑ insignificant

households get ∼4 bp worse yields, but mostly execute small trades in short-term bonds

Micro-level evidence: hedging vs pricing

- do dealers really use bond futures to hedge cash trades? more so than clients?

→ test by merging transaction-level data from cash (MiFIR) with futures market (EMIR)

$$NetVol_{it}^{f} = \alpha - \beta \times NetVol_{it}^{c} \times Dealer_i + \epsilon_{it}$$

where *NetVol* is the duration-weighted net trading volume (buy minus sell) of investor *i* on day *t* in German Bunds on the futures and cash market

	(1) all days	(2) excl. auctions, EoQ, fut.exp.	(3) excl. zeros
Client	0.10 [0.34]	0.04 [0.30]	0.09 [0.32]
Dealer	7.65*** [2.76]	16.10*** [3.34]	16.48*** [3.44]
FE Day	✓	✓	✓
FE LEI	✓	✓	✓
Observations	45296	36448	16014
Adjusted R^2	-0.001	0.009	-0.015

Sample covers the entire year 2020. (Naik and Yadav, 2003) provide similar evidence for UK dealers and (Fleming et al., 2024) for US dealers.

dealers hedge their cash exposure with futures, clients do not (not even those active on both markets)

Previous Eurex outages provide robustness checks

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

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

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

$\rightarrow$ those quotes are tightly linked to bond future prices

Less generous interpretation

$\rightarrow$ those quotes contain little inherent information

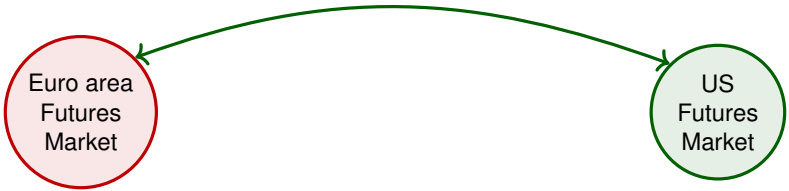
calculation methods behind quotes not disclosed, e.g. Bloomberg website describes quotes as "*a real-time composite based on executable and indicative quotes from multiple contributors [..] indicative of available consensus-forming prices, and designed for broad terminal use*"

we show: bond futures prices are vital input

US/EA Spillovers

jump back

do outages spill over between Eurex and CME?

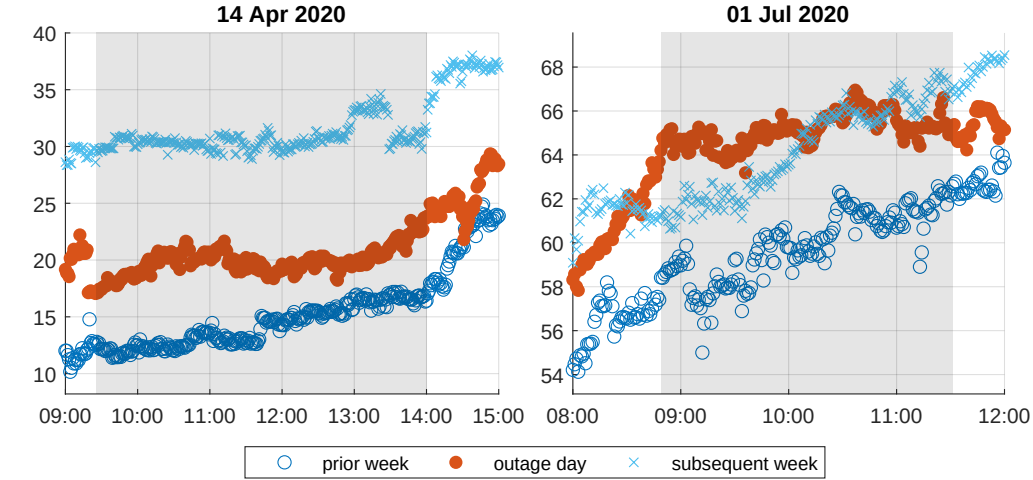


use Eurex outages to study EA→US

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)

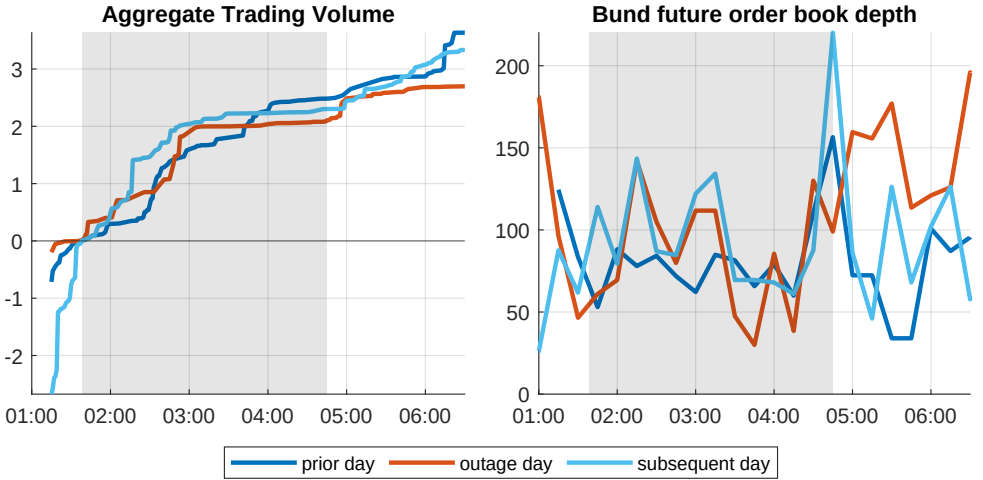
Eurex outage has little impact on US Treasury futures



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?

CME outage has little impact on Bund futures

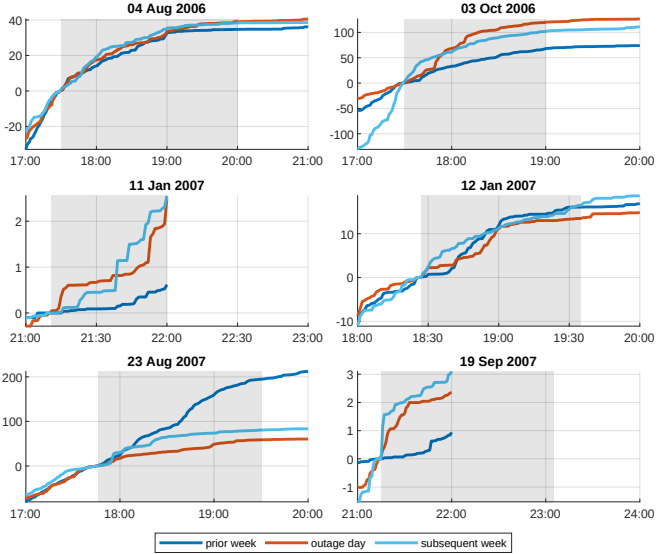


Eurex Activity during the CME Outage on 26 February 2019. The left panel shows the cumulative trading volume in all euro area bond futures on Eurex (in thousands of contracts, normalized to zero at the intraday time of the outage). The right panel shows the order book depth of 10-year German Bund futures (covering both sides of the first three levels of the order book; 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. In Central European Time, the outage occurred between 1:39 a.m. till 4:45 a.m. on 27 February 2019, marked by the grey area.

- no discernible decrease in Bund future liquidity

Previous CBOT outages also had little impact on Bund futures

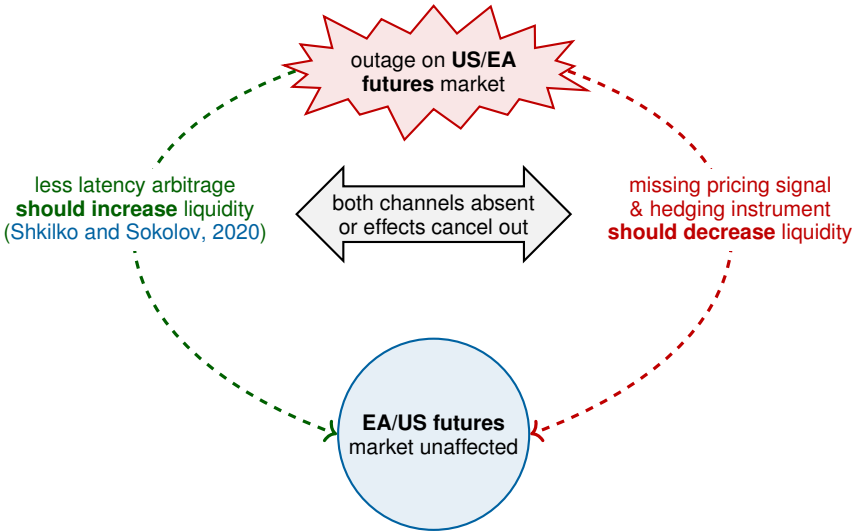
jump back



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

Micro-level mechanism



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