Outages in Sovereign Bond Markets

Mark Kerssenfischer [1] Caspar Helmus [1]

[1] Deutsche Bundesbank

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

Risk-free yield curve is key for all asset pricing

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

see literature on news (Fleming and Remolona, 1999; Andersen et al., 2003, 2007; Gürkaynak et al., 2020) and flows (Brandt and Kavajecz, 2004; Green, 2004; Pasquariello and Vega, 2007; Deuskar and Johnson, 2011; Gabaix and Koijen, 2021)

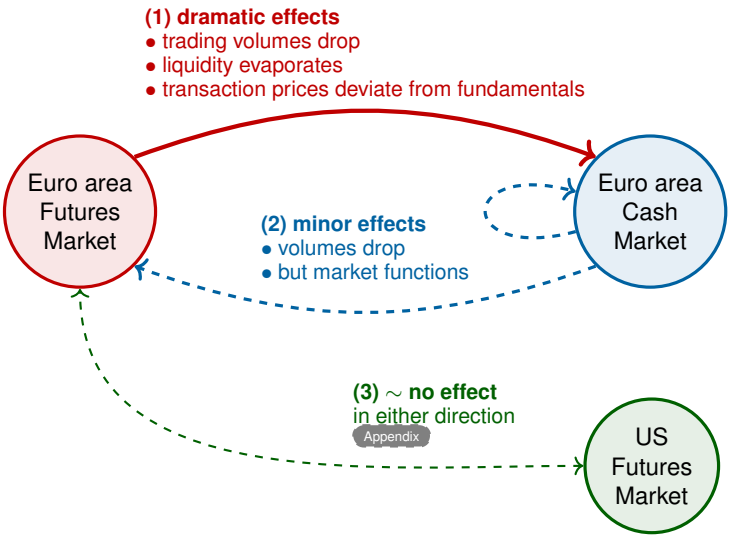
We study the ***who***, ***how*** and ***where*** of the price formation process

- which investor types?
- via which instruments?
- on what trading venues?

Exploit market outages as natural experiments

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

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

European Government Bond Market Structure

	Futures Market	Cash Market
# assets per country link	max. 4 futures	∼100 bonds
trading venue link	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	all intraday transactions & quotes	see next slide

Cash market data

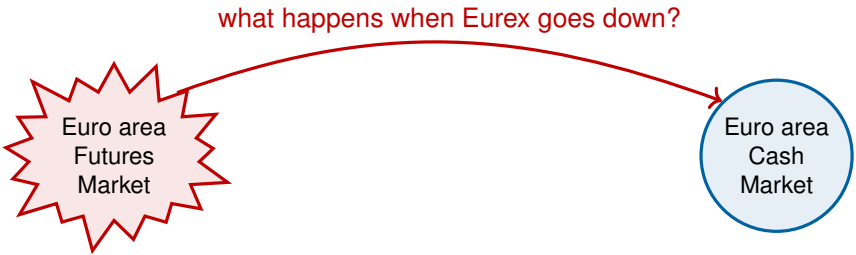
- start with non-anonymous transaction-level dataset
  MiFIR dataset (MiFID II); successor of "Bafin" dataset (MiFID I), see de Roure et al. (2019); Gündüz et al. (2023) and Bundesbank website

- **caveat**: trades in German bonds over-represented
  due to reporting obligation of trades by German counterparties and in German securities

⇒ **hence**: augment with external data
  - sourced directly from trading platforms (MTS, MTS BondVision, Tradeweb)
  - and interdealer brokers (TPICAP, BGC, GFI, Aurel)

- besides transactions, study cash market liquidity
  - executable quotes and volumes (MTS)
  - indicative quotes (Bloomberg, Refinitiv and TPICAP)

Futures Market Outages



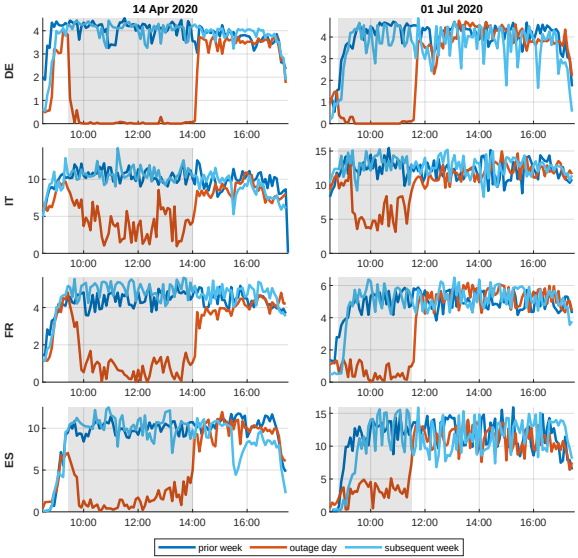
focus on two most recent outages:

- 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 for EGB cash trading with a CLOB

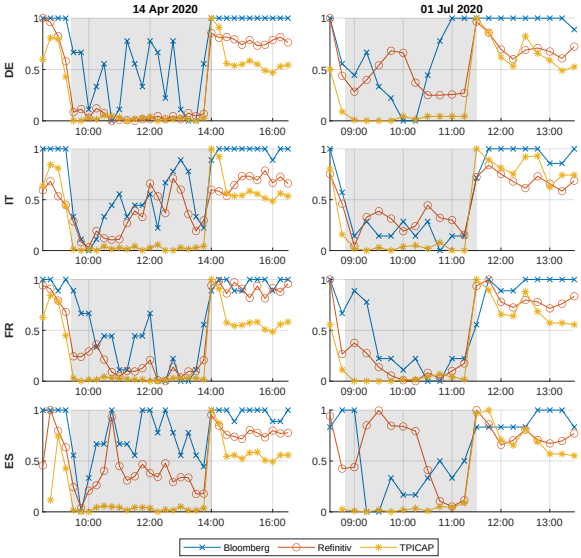
Look at total quoted volume (in billion Euro) of all bonds, across all three levels and both sides of the order book, at 5-minute snapshots.

Compare outage day with previous and subsequent week.

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

Liquidity most ‘robust’ for Italian bonds and short-term bonds Appendix

Indicative quotes become stale



Bloomberg & Refinitiv/Eikon: D2C venues

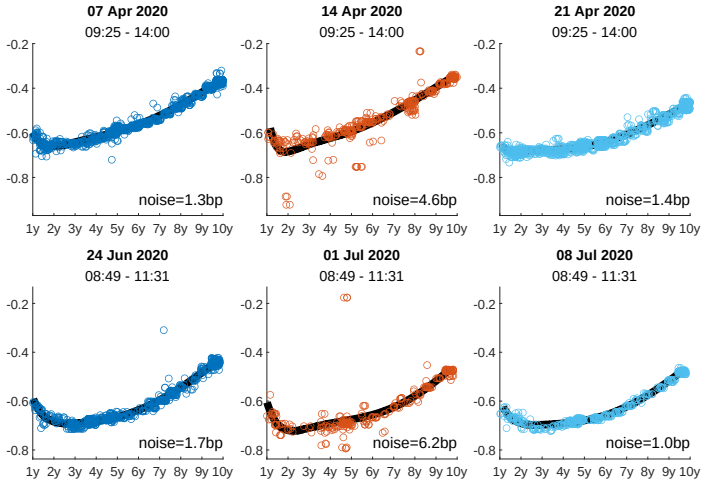
TPICAP: interdealer broker

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

Mispricing spikes



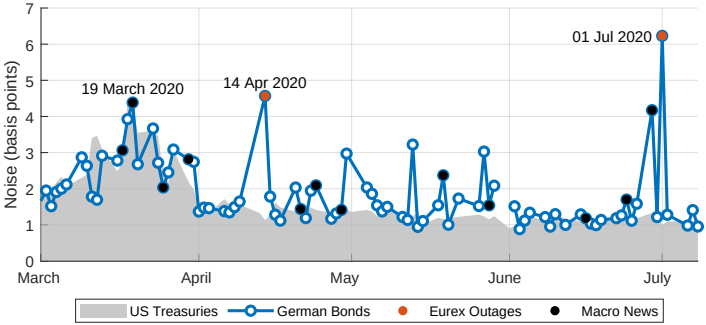
compare actual yields (implied by transaction prices) with fitted curve

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



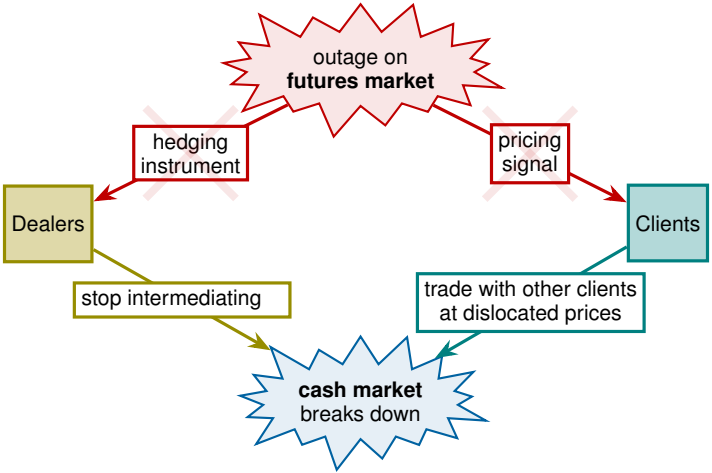
repeat previous exercise for all trading days between 1 March and 8 July 2020

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



Dealer/Client and Hedging/Pricing dichotomy

- explains **who** ...
  ... reduces trading activity
  → more sophisticated investors, e.g. dealers>clients
  ... commits pricing errors
  → less sophisticated investors
- explains **where** pricing errors occur
  → where these less sophisticated investors are active, e.g. regular exchanges > IDB
- explains **which** bonds & trades become mispriced (see paper)
  → small trades in short-term, non-CTD bonds
- explains **why** trading volumes and liquidity (see appendix) link link
  → drop *more* but pricing errors increase *less* for long-term bonds

Micro-level evidence: 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	0.376	0.164

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

dealers well-informed & patient

clients relatively uninformed & impatient (unaware of outage?)

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	0.444	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) absolute mispricing	(2) markup	(3) profit
Outage × Bank Dealer	0.61***	0.17*	1.52**
Outage × Bank Non-Dealer	1.90***	0.64	-1.31*
Outage × NBFI	1.24**	0.47**	0.91
Outage × Investment Fund	0.44**	-0.59***	-2.61
Outage × Hedge Fund	2.62***	2.75***	1.53
Outage × ICPF	0.27	-0.52***	-5.85*
Outage × NFC	1.78	-1.29	-1.14
Outage × Official	0.20	-0.30	-3.08
Outage × Household	4.29***	-4.03***	-2.47*
FE Minute	✓	✓	✓
FE ISIN	✓	✓	✓
Observations	6083	6083	6083
Adjusted R^2	0.165	0.051	-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)

$$NetVol^f_{it} = \alpha + \beta \times NetVol^c_{it} \times Dealer_i + \epsilon_{it}$$

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

prima facie evidence: almost all dealers trade bond futures, few clients do

	Eurex-Active	Eurex-Inactive	Total
Dealer	29	2	31
Client	30	481	511
Total	59	483	542

Data refers to investors with cash Bund trades on six selected days in 2020. Investors are aggregate to group-level. 31 dealers matched to >100 LEIs.

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

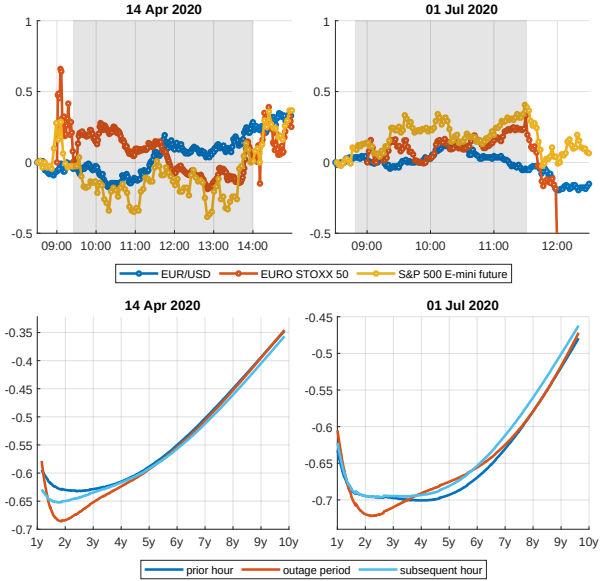
	(1) all days	(2) excl. auctions, EoQ and fut.exp.
Client	-0.00 [0.01]	-0.00 [0.01]
Dealer	-0.24*** [0.08]	-0.33*** [0.05]
FE Day	✓	✓
Observations	22749	17244
Adjusted R^2	0.005	0.007

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

Comparison of Eurex Outage to Other Shocks

Type of Shock	Similarities	Differences
Dealer capacity shock (Duffie et al., 2023)	dealers cannot hedge inventory risk, stop intermediating	
Liquidity supply shock (Goldberg, 2020)	yield curve noise spikes and dealers take on less inventory than usual	
Information asymmetry & network shock (Hagströmer and Menkveld, 2019; Pintér et al., 2024)	spike in mispricing largest for least sophisticated investors	
Urgency shock (Menkveld et al., 2017)	market share increases for high-cost-high-immediacy venues (like exchanges), decreases for low-cost-low-immediacy venues (like OTC)	aggregate trading volumes *decline* during the outage
Fire sales (Shleifer and Vishny, 2011)	investment funds sell assets at dislocated prices	only true for investment funds, hedge funds *profit* from the outage

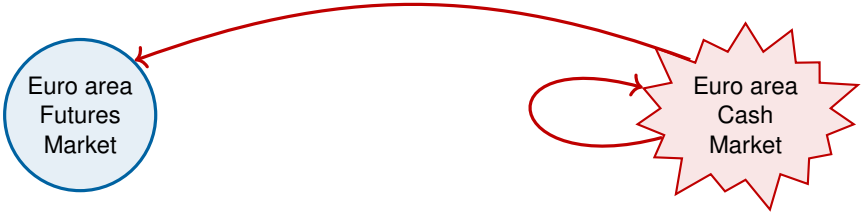
Ruling out Alternative Explanations



1. market panic, dash for cash, flight to safety/liquidity?
   - × barely any movement in Eurostoxx, S&P 500 E-mini, USD/EUR (top figure)
   - × noise *around* yield curve increases, curve *itself* barely changes (bottom figure)
2. selling pressure (Feldhütter, 2012)
   - × large trades do not occur at prices below fair value (or vice versa) (see paper)
3. malfunctioning trading algos
   - × mispricing too widespread, bigger if investors not active on Eurex

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

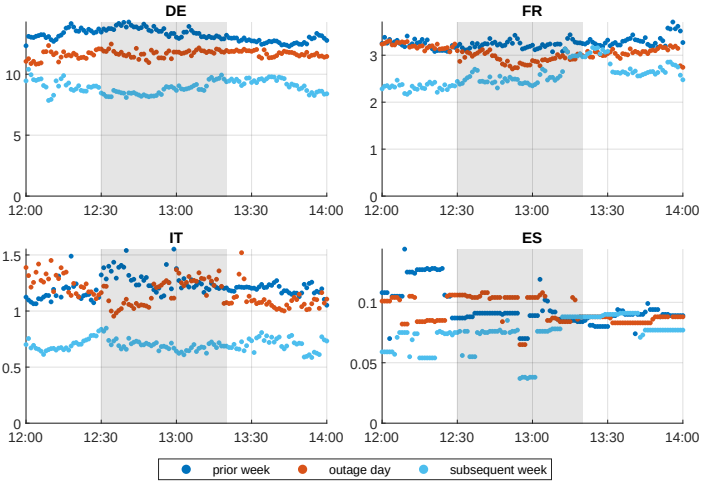
	MTS 12 Jan 2010 8:00-10:35	Bloomberg 17 Apr 2015 9:20-10:10	FWB 27 May 2015 8:00-11:00	Brokertec 11 Jan 2019 19:43-21:35	MTS 26 Jul 2019 12:30-13:20	Pooled
Cash market						
Volume	-1.33***	-4.45***	-0.43*		-2.35*	-1.46***
	[0.11]	[0.13]	[0.10]		[0.69]	[0.44]
#Trades	-0.17***	-0.38	-0.08		-0.28***	-0.17***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

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

futures market barely affected:
trading activity ↓ slightly, illiquidity ↑ only .05 (Amihud) and .09 (Roll) std.dev.

cash→futures outage effect orders of magnitude smaller than vice versa

Example: MTS outage on 26 July 2019



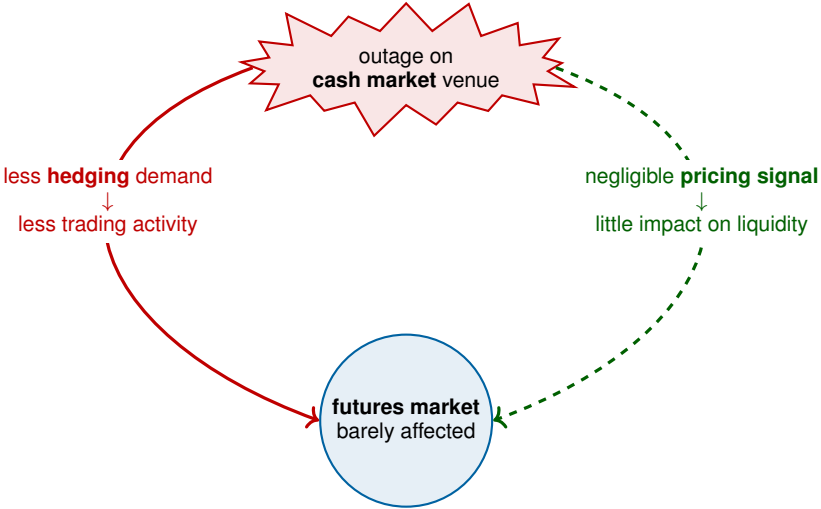
for most recent outage, we can directly observe liquidity on Eurex

recall: Eurex outages reduce MTS liquidity by 50-100%; what about the other way around?

Compare number of 10-year future contracts (in thousands), quoted on first fifteen levels on both sides order book on outage day with previous and subsequent week.

virtually no effect of MTS outage on Eurex, even for Italy

Micro-level mechanism



see regression results

Summary

Bond futures are key for EGB cash market functioning

- lack of hedging instrument: well-informed dealers stop intermediating
- lack of pricing signal: clients trade at dislocated prices

Asymmetry: little outage effect from cash $\longrightarrow$ future market

- less hedging demand $\rightarrow$ less trading; liquidity barely affected
- price discovery and liquidity provision one-way street from futures $\longrightarrow$ cash market

No outage spillovers between US $\longleftrightarrow$ Euro area bond futures

in contrast to strong & swift price spillovers

Contribution to literature

Competing theories of liquidity spillovers:

× 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; Veldkamp, 2006; 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

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

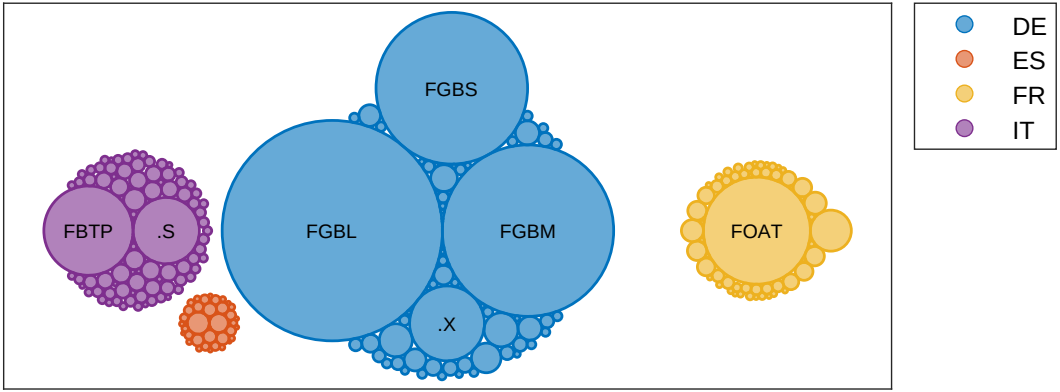
✓ robust to outage of individual venues

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

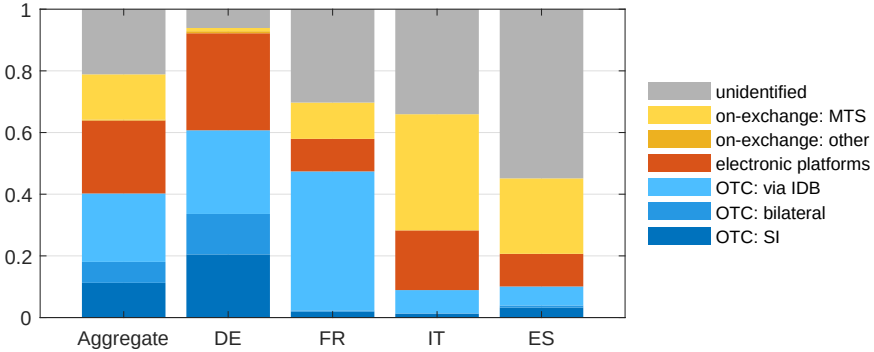
Cash market "fragmentation" across bonds

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 "fragmentation" across venue types

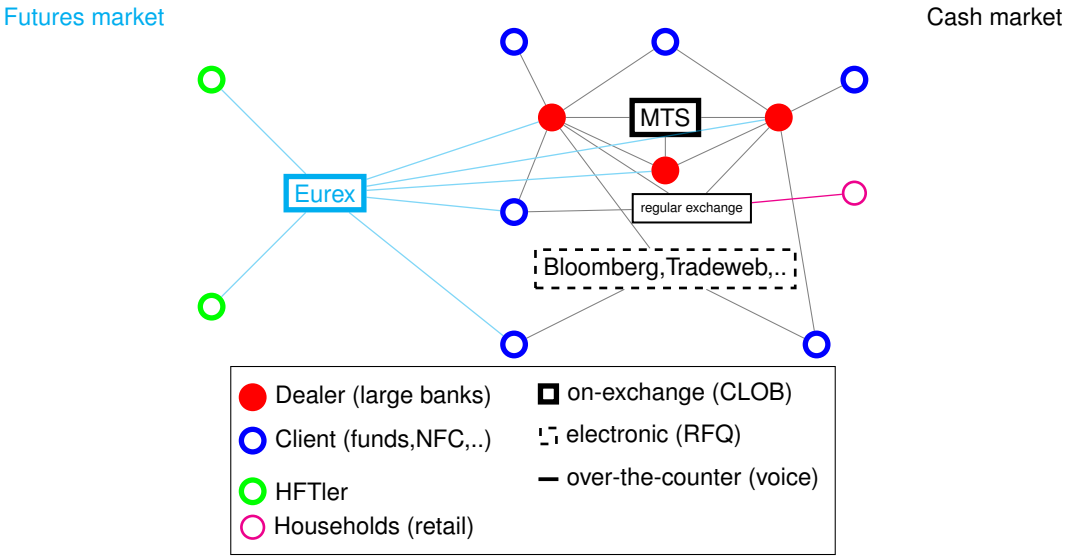


market shares of cash trading venue types at aggregate and country-level, based on our transaction dataset for all four non-outage days (i.e. April 7 and 21, June 30 and July 8, 2020)

"IDB" refers to interdealer brokers, "SI" refers to systematic internalisers and "other exchanges" refer to regular stock exchanges.

Illustrative EGB Market Structure

jump back



Descriptives: # of Investor Types

	Total	Active on Eurex
Bank Dealer	31	29
Bank Non-Dealer	80	12
NBFI	45	6
Investment Fund	225	5
Hedge Fund	67	6
ICPF	56	1
NFC	20	
Official	16	
HH	1	
Total	541	59

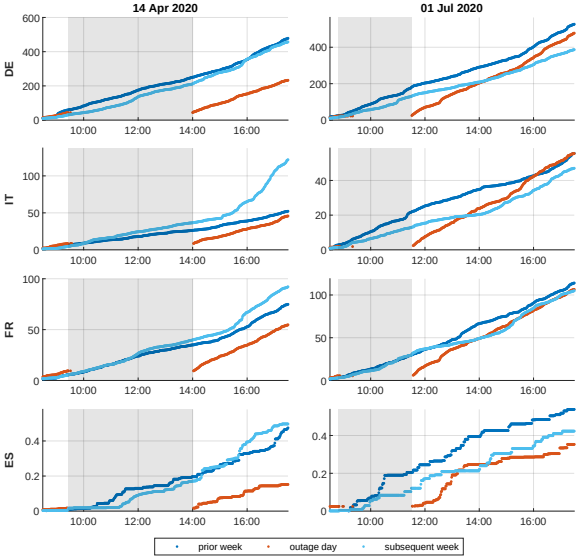
Number of Investors by Type. Data refers to investors with cash Bund trades on six selected days in 2020. Investors are aggregated to group-level. 31 dealers matched to >100 LEIs. The category "households" comprises an unknown number of retail investors, as these are not uniquely identifiable via a LEI.

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

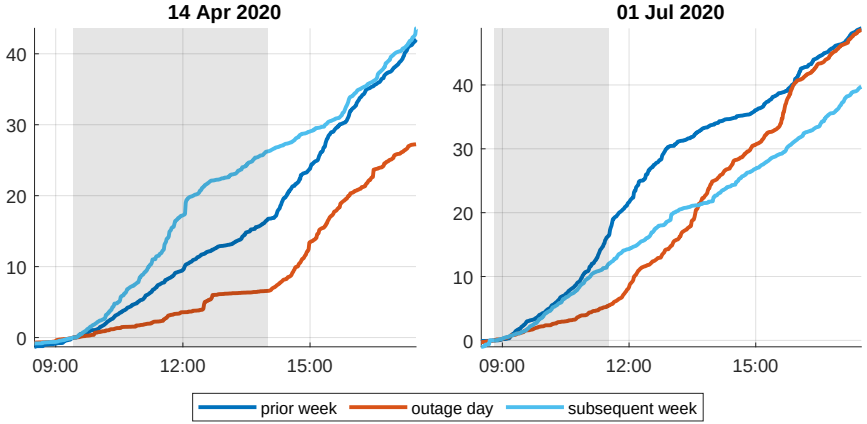


Cumulative trading volume in 10-year bond futures.

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

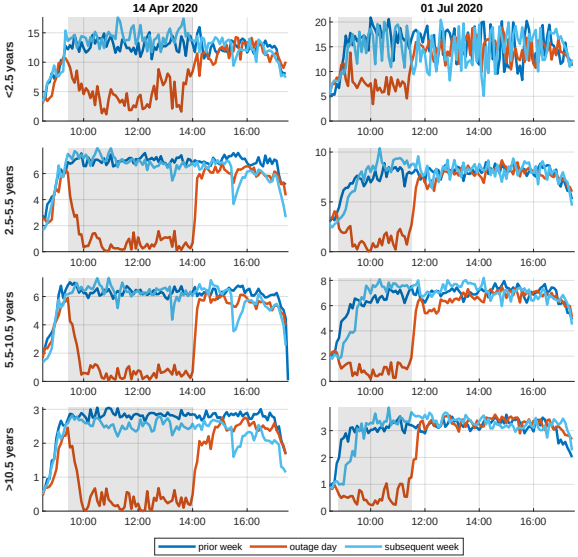
	(1)	(2)
Outage	-3.16**	-3.65**
CTD		2.73***
OTR		1.15**
Zero Coupon		-1.36***
log(Years to Maturity)		0.88***
log(Years since Issuance)		-1.15***
Outage × CTD		-1.30*
Outage × OTR		-1.46**
Outage × Zero Coupon		0.69*
Outage × log(Years to Maturity)		0.06
Outage × log(Years since Issuance)		0.31
FE Day	✓	✓
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 maturities

jump back

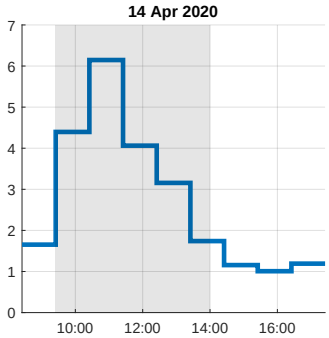


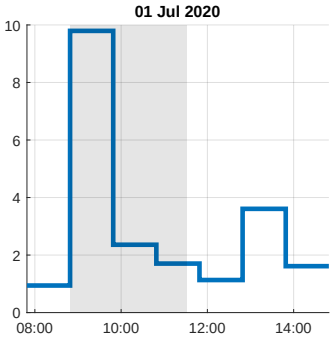
Instead of countries, compare MTS order book depth across maturity buckets

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

short-term bonds most ‘robust’

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

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 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

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

Size of Futures vs Cash Bond Market in Euro Area

jump back

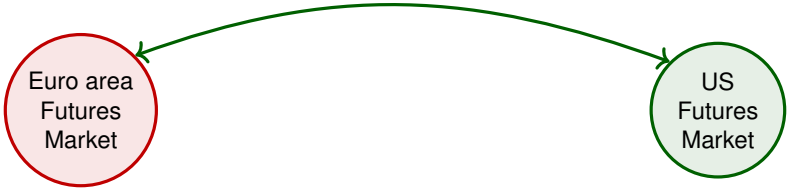
Country	Future Volume (billion €)	Cash Volume (billion €)	Ratio Future/Cash
Germany	72,044	7,404	9.7
France	7,745	5,435	1.4
Italy	8,367	7,197	1.2
Spain	21	2,002	.01

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.

US/EA Spillovers

jump back

do outages spill over between Eurex and CME?

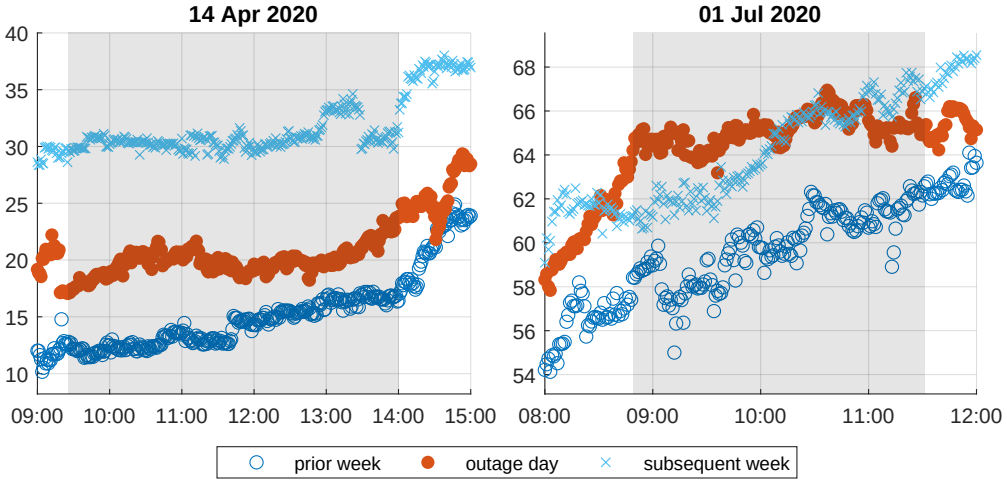


use Eurex outages to study EA→US

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)

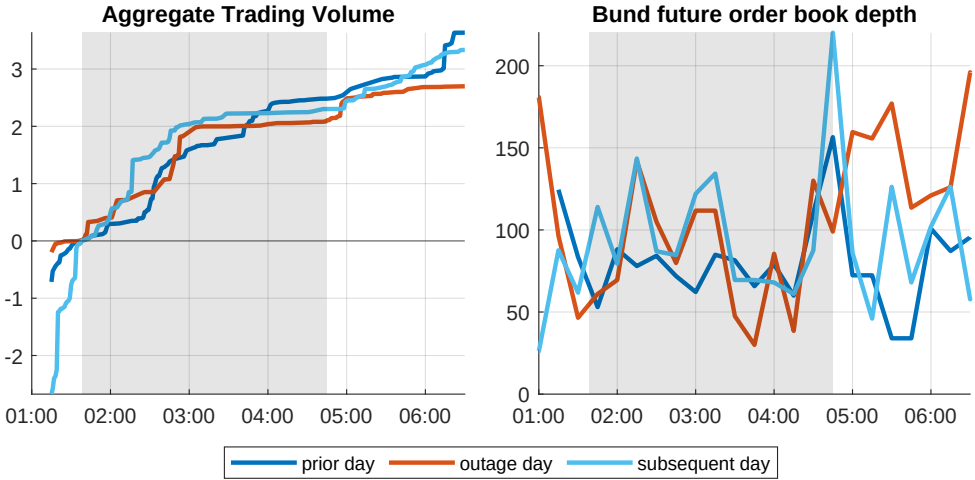
Eurex outage has little impact on US Treasury futures



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

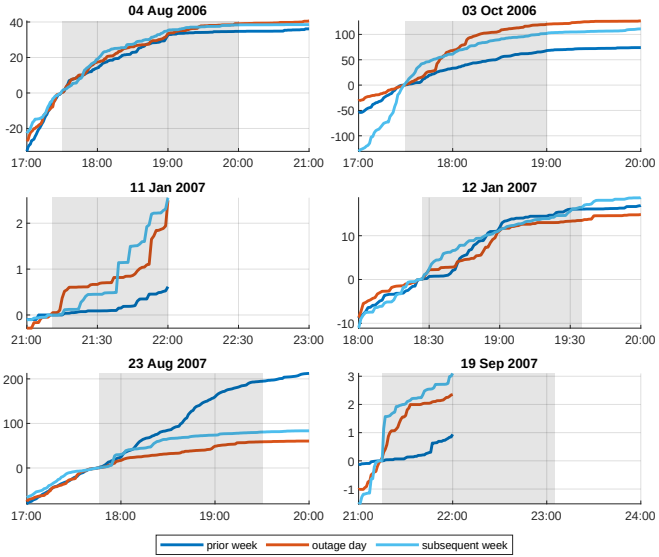


Eurex Activity during the CME Outage on 26 February 2019. The left panel shows the cumulative trading volume in all euro area bond futures on Eurex (in thousands of contracts, normalized to zero at the intraday time of the outage). The right panel shows the order book depth of 10-year German Bund futures (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

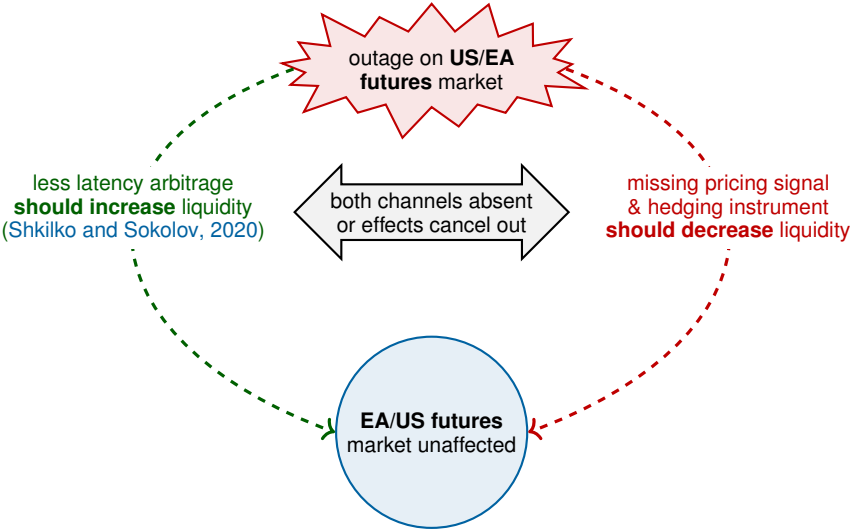
jump back



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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