# Collateral Choice

EEA-ESEM Barcelona 2023

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August 29, 2023

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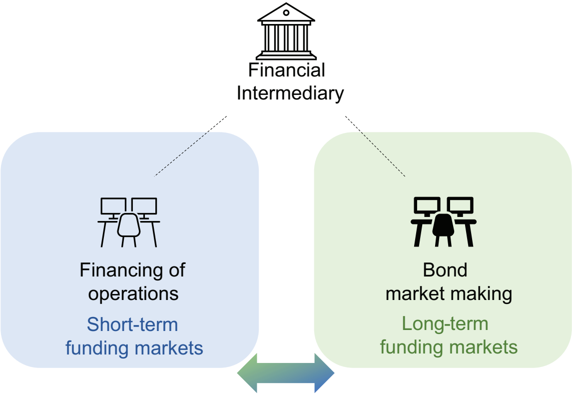
# Funding markets



Financial Intermediary

Financing of operations

Short-term funding markets

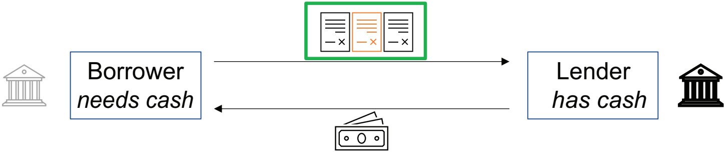
Bond market making

Long-term funding markets

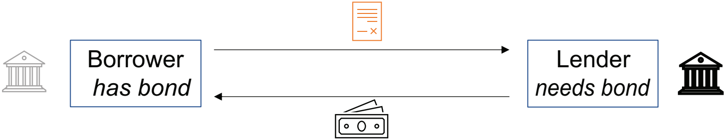
connected by the secured, short-term funding instrument, the repurchase agreement (**repo**)

# Short-term funding markets

General collateral (GC) repo transaction:

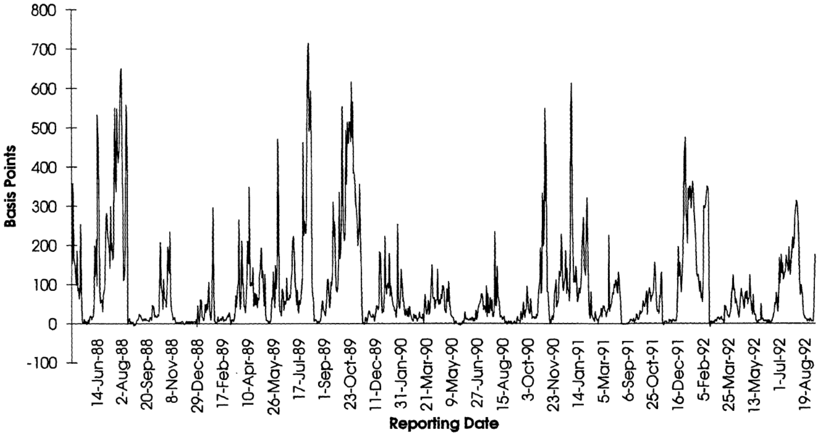


Special repo (securities lending) transaction:



- Transactions look similar but have a different economic motive
- Interest on special repo < interest on GC repo.

# Duffie (1996)


800
700
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Basis Points
14-Jun-88
2-Aug-88
20-Sep-88
8-Nov-88
29-Dec-88
17-Feb-89
10-Apr-89
26-May-89
17-Jul-89
1-Sep-89
23-Oct-89
11-Dec-89
31-Jan-90
21-Mar-90
9-May-90
27-Jun-90
15-Aug-90
3-Oct-90
23-Nov-90
14-Jan-91
5-Mar-91
6-Sep-91
25-Oct-91
16-Dec-91
5-Feb-92
25-Mar-92
13-May-92
1-Jul-92
19-Aug-92
Reporting Date

# Collateral choices

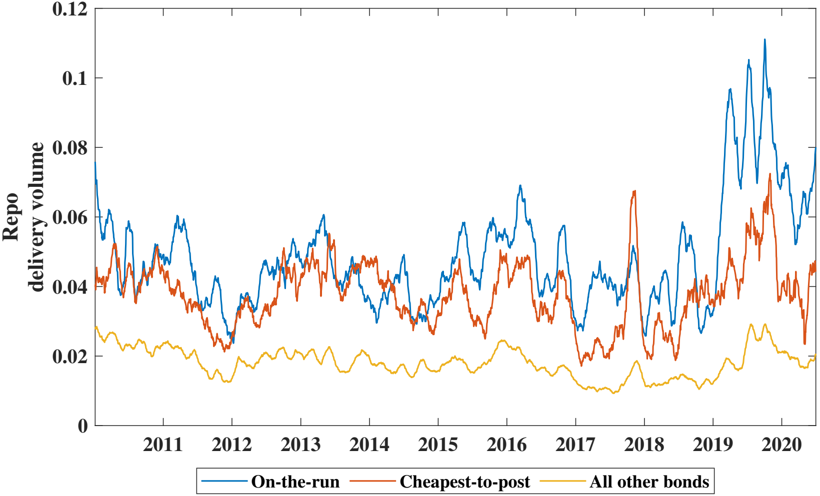

Figure: **Repo delivery volumes**

# Focus of this paper and results preview

## Research Question 1:

Which **collateral** is **chosen** in the GC market? Why?

- Collateral choices are driven by **availability** and **opportunity cost**.

## Research Question 2:

How are **collateral choices connected to the bond market**?

- Search **frictions** cause market makers to use 'expensive' on-the-run bonds in GC funding.
- This **inefficiency** adds to inventory costs and leads to higher bond market spreads.

## Research Question 3:

Do short-term funding market dynamics help us explain **bond pricing patterns**?

- Results provide an explanation why there is an *on-the-run phenomenon* in the United States but not in Europe.

# Contribution to literature

**Short-term funding markets**

- First systematic analysis of collateral choices in the main short-term funding market (repo market).
- Bartolini et al. (2011): GC rates involving U.S. Treasuries include a collateral rent which other asset classes do not offer.
- Song and Zhu (2019) analyze a different form of collateral choice related to mortgage-backed securities.

**Link between short-term and long-term funding markets**

- First paper showing how collateral choices in the repo market connect to a bond's market liquidity.
- Seminal work by Duffie (1996) and Krishnamurthy (2002); more recently, e.g., Huh and Infante (2021) and D'Amico and Pancost (2022).
- Related literature on auction cycles: Keane (1996) and more recently, e.g., Lou, Yan, and Zhang (2013), D'Amico, Fan, and Kitsul (2018), and Sigaux (2018).

# Setting

# Why care about short-term funding markets?

- **Liquidity frictions** can cause disruptions in the financial markets and lead to instability.
- Interbank rates are **reference rates** for the **real sector** such as mortgages and for interest rate / derivatives products.
- Money markets are important vehicles for the implementation of **monetary policy** (Ballensiefen, Ranaldo, and Winterberg, 2023).

Euro area: Unique data set of **transaction-level** data for the period from January 2010 to June 2020.

US repo market for **comparison** based on FED data.

market relevance data overview

# Drivers of collateral choice

# Collateral availability

## Net supply of collateral assets

- **Sources of variation** in availability / in net supply:
  - Auction cycles
  - Asset scarcity induced by QE
  - Buy-and-hold investors
- **Scarcity** is the *counterpart* to availability.

# Time since last auction

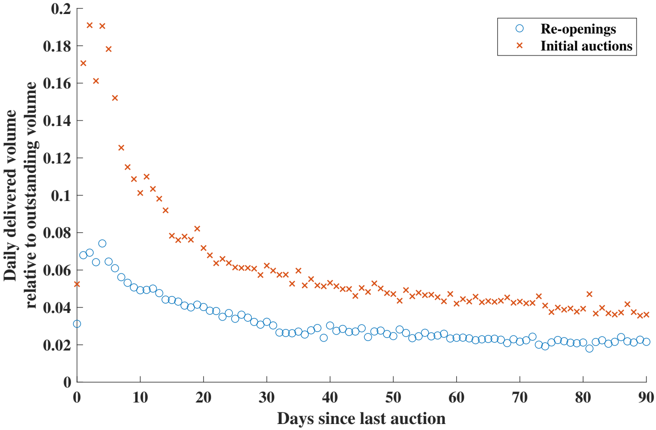

Figure: **Time since last government bond auction**

auction size on-the-run status

# Quantitative Easing

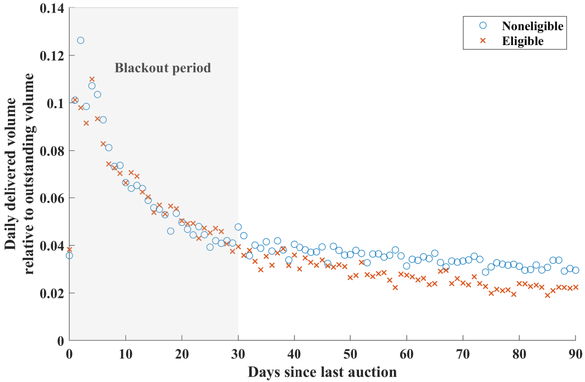

Figure: **Eligibility for Quantitative Easing**

# Two measures of collateral opportunity cost

Posting a bond in a GC repo which is in high demand in the special segment due to its **convenience yield** is costly (Ballensiefen and Ranaldo, 2023).

**Trade-off**: **search frictions** in special segment vs **higher rates** in GC segment.

**Cheapest-to-post spread**:
opportunity cost of delivering a bond different to the CTP bond into the GC trade

$$CTP\ spread_{i,t} = reporate^{special}_{CTP,t} - reporate^{special}_{i,t} \tag{1}$$

**Repo specialness**:
opportunity cost of engaging in a GC trade as opposed to a special trade

$$Repo\ specialness_{i,t} = reporate^{GC}_{basket,t} - reporate^{special}_{i,t}. \tag{2}$$

CTP spread · repo specialness · quarter-ends · haircut

# CTP spread and on-the-run status

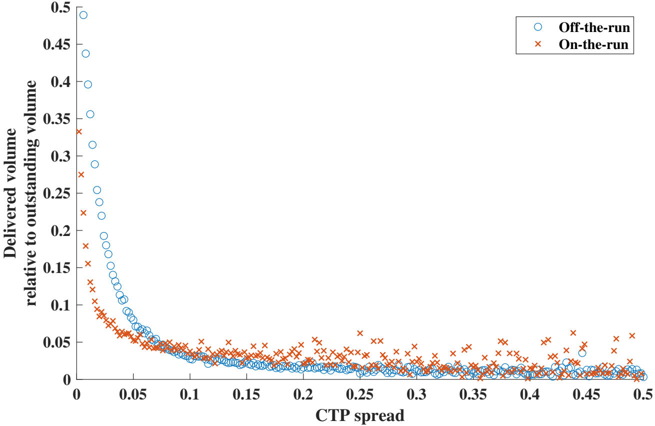

Figure: **CTP spread and on-the-run status**

repo deliveries and repo specialness | high and low CTP spread | high and low interest rates

# Empirical results take-away

Table: Collateral availability and opportunity cost

| | (1) Delivery volume |
|---|---|
| Auction size | 0.038* |
| Auction size $\cdot D^{Initial}$ | 0.160*** |
| Time since auction | −0.018* |
| Time since auction $\cdot D^{Initial}$ | −1.716*** |
| $D^{OnTheRun}$ | 0.809*** |
| Time since QE eligibility | −0.455*** |
| $D^{CTP}$ | 0.387*** |
| CTP spread | −0.876*** |
| $N$ | 613,534 |
| $R^2$ | 0.248 |
| FE | Yes |
| Constant | Yes |

↑ collateral availability ⇒ ↑ delivered volume

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**On-the-run** bonds are more frequently delivered than **CTP** securities.

detailed results | aspects of collateral availability | additional tests

# Market maker's decision problem

# Theory

## Inventory-type model a la Stoll (1978) linking the collateral choice to the bond market

- As a market maker, the dealer posts bid and ask quotes. The **spread compensates** him for each trade's cost $C_i$.
- Dealer and investors have similar information about the intrinsic government bond value, no asymmetric information as in Kyle (1985).
- Dealer participates in government bond auctions and builds a **bond inventory** to
    - distribute to non-participating investors ("*distribution phase*"),
    - deal with long-term order flow ("*market-making phase*").
- During distribution phase, the dealer deviates from optimal long-term portfolio (→ **inventory risk**). optimal portfolio weight buy-and-hold investor share
- Dealer needs to fund additional bond holdings via **repos**.

# Theory: funding costs

- Funding cost depend on the dealer's market choice.
- Special segment is subject to frictions increasing in size.
- Dealer earns repo specialness $OC_i$ by posting OTR bonds in special trades.
- Trade-off determines optimal market choice $\theta^*_{Special}$ :

$$\theta^*_{Special} = (\frac{OC_i}{ab})^{\frac{1}{b-1}} \quad (3)$$

- Determines the funding cost $R_F$ :

$$R_F = R_{GC} - \theta_{Special} OC_i. \quad (4)$$

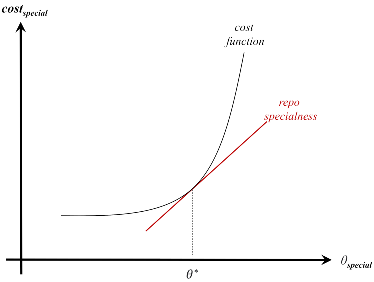


Figure: **Optimal funding decision**

# Market maker's decision problem

$$EU(\tilde{W}^*) = EU(\tilde{W}). \tag{5}$$

with

$$\tilde{W}^* = W_0[1 + \tilde{R}^*] \tag{6}$$

$$\tilde{W} = W_0(1 + \underbrace{\tilde{R}^*}_{\substack{\text{return}\\ \text{initial}\\ \text{portfolio}}}) + \underbrace{Q_i(1 + \tilde{R}_{OTR} - OC_i)}_{\substack{\text{change}\\ \text{trading}\\ \text{portfolio}}} - \underbrace{(Q_i - C_i)(1 + R_F)}_{\substack{\text{change}\\ \text{financing}\\ \text{cost}}}. \tag{7}$$

Solving for $C_i$ leads to:

$$C_i = \frac{\frac{1}{2}aQ_i^2\text{Var}(\tilde{R}_{OTR}) + aQ_iQ_{OTR}\text{Var}(\tilde{R}_{OTR}) + Q_iOC_i(1 - \theta_{Special})}{(1 + R_{GC} - \theta_{Special}OC_i)}. \tag{8}$$

model framework | model derivation | derivation of bid-ask spread

# Bond market estimation

Table: Bond market spread

| | (1) Relative spread *t+1* |
|---|---|
| Delivery volume | 0.879** |
| Repo specialness | 0.252*** |
| $Var(\tilde{R}_i)$ | 0.224*** |
| Quoted depth difference | 2.963*** |
| $N$ | 253,521 |
| $R^2$ | 0.736 |
| FE | Yes |

↑ size of GC funded position ⇒ ↑ spread

↑ opportunity cost ⇒ ↑ spread

# Bond market implications

# On-the-run bond premium in the U.S.

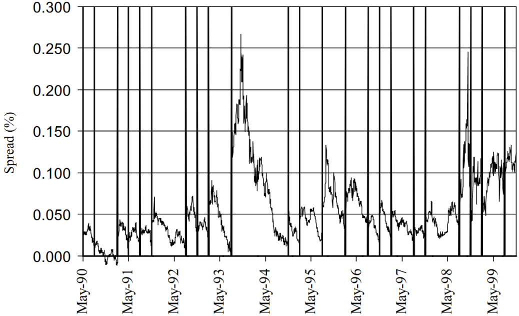
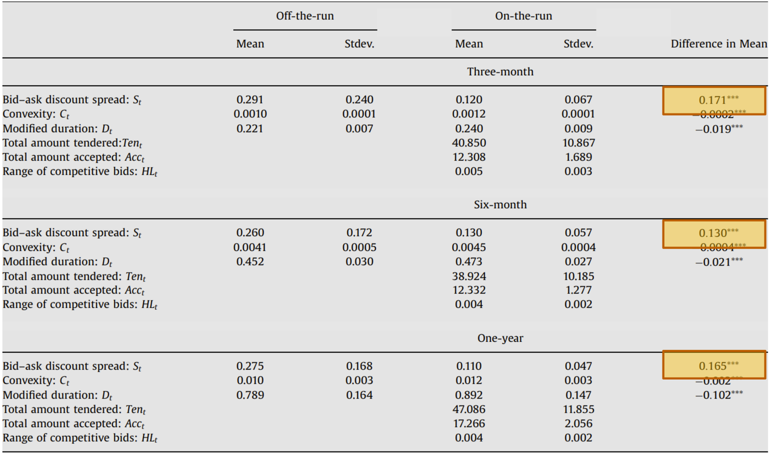


Fig. 2. Yield spread between bond and old-bond. The vertical lines mark auction dates.

Figure: On-the-run premium in the U.S. (Krishnamurthy, 2002, p. 465)

# Superior liquidity in the U.S. on-the-run bond?



| | Off-the-run | | On-the-run | | |
|---|---|---|---|---|---|
| | Mean | Stdev. | Mean | Stdev. | Difference in Mean |
| | | | Three-month | | |
| Bid–ask discount spread: $S_t$ | 0.291 | 0.240 | 0.120 | 0.067 | 0.171$^{***}$ |
| Convexity: $C_t$ | 0.0010 | 0.0001 | 0.0012 | 0.0001 | −0.0002$^{***}$ |
| Modified duration: $D_t$ | 0.221 | 0.007 | 0.240 | 0.009 | −0.019$^{***}$ |
| Total amount tendered:$Ten_t$ | | | 40.850 | 10.867 | |
| Total amount accepted: $Acc_t$ | | | 12.308 | 1.689 | |
| Range of competitive bids: $HL_t$ | | | 0.005 | 0.003 | |
| | | | Six-month | | |
| Bid–ask discount spread: $S_t$ | 0.260 | 0.172 | 0.130 | 0.057 | 0.130$^{***}$ |
| Convexity: $C_t$ | 0.0041 | 0.0005 | 0.0045 | 0.0004 | 0.0004$^{***}$ |
| Modified duration: $D_t$ | 0.452 | 0.030 | 0.473 | 0.027 | −0.021$^{***}$ |
| Total amount tendered: $Ten_t$ | | | 38.924 | 10.185 | |
| Total amount accepted: $Acc_t$ | | | 12.332 | 1.277 | |
| Range of competitive bids: $HL_t$ | | | 0.004 | 0.002 | |
| | | | One-year | | |
| Bid–ask discount spread: $S_t$ | 0.275 | 0.168 | 0.110 | 0.047 | 0.165$^{***}$ |
| Convexity: $C_t$ | 0.010 | 0.003 | 0.012 | 0.003 | −0.002$^{***}$ |
| Modified duration: $D_t$ | 0.789 | 0.164 | 0.892 | 0.147 | −0.102$^{***}$ |
| Total amount tendered: $Ten_t$ | | | 47.086 | 11.855 | |
| Total amount accepted: $Acc_t$ | | | 17.266 | 2.056 | |
| Range of competitive bids: $HL_t$ | | | 0.004 | 0.002 | |

Figure: On-the-run liquidity in the U.S.(Pasquariello and Vega, 2009, p.9)

# Superior liquidity in the euro area on-the-run bond?

Table: Liquidity measures for on-the-run and off-the-run bonds

| | (1) Short-term | (2) Medium-term | (3) Medium-term floating | (4) Long-term | (5) Long-term inflation-linked |
|---|---|---|---|---|---|
| Bid-ask spread | | | | | |
| On-the-run | 0.45 | 0.33 | 0.14 | 0.54 | 0.78 |
| Off-the-run | 0.45 | 0.28 | 0.12 | 0.35 | 0.54 |
| Difference | −0.00 | $-0.05^{***}$ | $-0.02^{***}$ | $-0.19^{***}$ | $-0.24^{***}$ |
| | (−0.16) | (−24.11) | (−3.74) | (−36.07) | (−6.95) |
| Daily bond trading quantity (mm) | | | | | |
| On-the-run | 142.0 | 15.2 | 110.0 | 62.7 | 42.6 |
| Off-the-run | 61.9 | 14.2 | 51.7 | 28.9 | 28.3 |
| Difference | $-80.2^{***}$ | $-1.0^{***}$ | $-58.7^{***}$ | $-33.8^{***}$ | $-14.3^{***}$ |
| | (−55.50) | (−3.48) | (−32.27) | (−73.97) | (−19.98) |

# One explanation: different funding choices

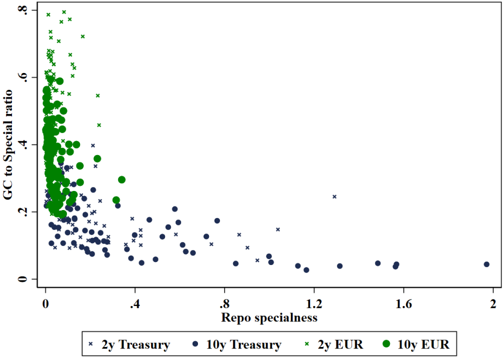


Figure: Repo financing shares in the U.S. vs the euro area

# Conclusion

# Conclusion

**First systematic analysis of collateral choices in one of the main short-term funding market.**

- **Novel link** between the repo market and the underlying bond market.
- Results suggest that repo collateral choices are one reason for the **time-variation in bond market spreads**.
- Highlight the **important role of financial intermediaries** in connecting short-term and long-term funding markets:

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# Appendix: Different market turnovers

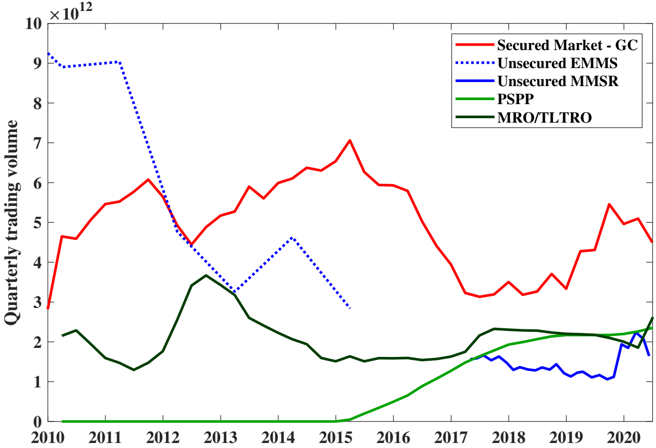

Figure: **Different market turnovers**

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# Appendix: Repo market

## European repo market particularly well suited for analysis

- **Largest repo market worldwide:** EUR 9+ trillion in outstanding contracts.
- Market characteristics **eliminate many confounding factors:** term premia, counterparty, and currency risk.
- Unique data set of **transaction-level** data for the period from January 2010 to June 2020 ($\sim$ 50% of all trades).

## U.S. repo market for comparison

- USD 4+ trillion in outstanding contracts.
- Repo trading is **distributed** over different platforms and market types.
- Fed's Primary Government Securities Dealers Reports (**Form FR 2004**) for 2 and 10-year OTR U.S. Treasury securities.

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# Appendix: Data overview

**Europe**

- Unique data set of GC repo trades on MTS platform for the period from **January 2010 to June 2020**.
- Near-total universe of **Italian** repos, plus trade-level information for **other euro area countries**.

data description data breakdown baskets description

**U.S.**

- **Primary Dealer Statistics** from the Federal Reserve Bank of New York.
- Monthly data reported by primary dealers on **Form FR2004**.
- Data is aggregated by various criteria but allows for differentiation between **on-the-run and off-the-run bonds**.

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# Appendix: Data description

Focus is on the European repo market which is the largest repo market worldwide.

- On each day, for each basket and bond, I compute the trade volume for which a **bond served as collateral** (*relative* to the bond's outstanding volume).
- For all *bonds*, I add information on e.g., auctions, re-openings, and haircuts. I also classify collateral as eligible and noneligible for QE purchases by the ECB.
- For each *basket*, I derive a daily list of bonds that are eligible to be pledged as collateral. This allows me to identify the cheapest-to-post (**CTP**) bond, which is the bond with the highest special repo rate (lowest opportunity cost).

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# Appendix: Breakdown of the euro area data

Table: Breakdown of the repo data

| | Transactions (in million) | Volume (in euro trillion) | Transactions (share in %) | Volume (share in %) |
|---|---|---|---|---|
| **General collateral euro repos** | 1.57 | 77.94 | 100.00% | 100.00% |
| Overnight | 0.40 | 15.29 | 25.13% | 19.62% |
| Tomorrow-next | 0.65 | 30.39 | 41.61% | 38.99% |
| Spot-next | 0.42 | 24.70 | 26.41% | 31.69% |
| Other term types | 0.11 | 7.57 | 6.85% | 9.71% |
| Borrower-initiated trade | 0.86 | 41.68 | 54.87% | 53.48% |
| Lender-initiated trade | 0.61 | 30.26 | 38.83% | 38.82% |
| Repo BTP | 0.81 | 39.72 | 51.67% | 50.96% |
| Repo BOT | 0.28 | 12.95 | 17.65% | 16.62% |
| Repo CCT | 0.20 | 10.21 | 12.90% | 13.09% |
| Repo BTP€i | 0.16 | 7.99 | 10.36% | 10.25% |
| Repo CTZ | 0.11 | 6.11 | 6.76% | 7.84% |
| Other baskets | 0.01 | 0.97 | 0.66% | 1.24% |
| **On-the-run in GC and special** | | | 100.00% | 100.00% |
| On-the-run deliveries in GC | 0.33 | 17.94 | 24.14% | 44.37% |
| On-the-run special segment | 1.04 | 22.49 | 75.86% | 55.63% |

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# Appendix: Government bond types and auction cycles

## Each bond type carries its own dedicated GC basket on MTS.

- Treasury bills (**BOTs**) are short-term zero-coupon discount bonds with maturities of up to one year, BOTs have no reopenings.
- Treasury bonds (**BTPs**) are medium- to long-term bonds with a fixed coupon paid semi-annually, BTP bonds are regularly reopened.
- Treasury bonds linked to inflation (**BTPs€i**) are medium to long-term, inflation-indexed bonds (i.e., indexed to euro-zone inflation). BTPs€i bonds are regularly reopened.
- Treasury certificates indexed to 6-month Euribor (**CCTs**) are medium-term bonds with a floating coupon paid semi-annually, CCT bonds are regularly reopened.
- Zero coupon bonds (**CTZs**) are zero-coupon discount bonds with maturities of two years, CTZ bonds are regularly reopened.

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# Appendix: Auction size

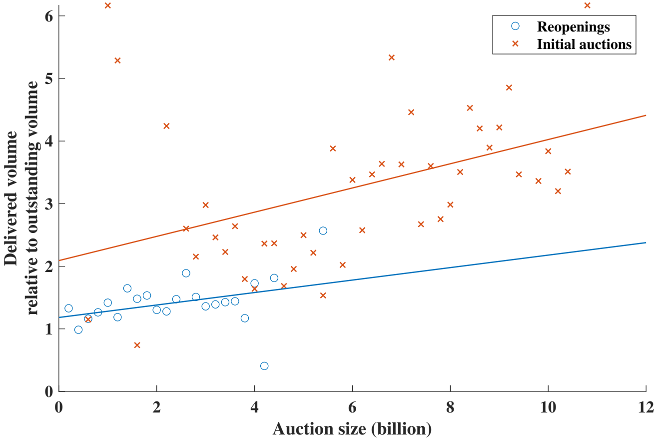

Figure: **Auction size**

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# Appendix: On-the-run status remaining

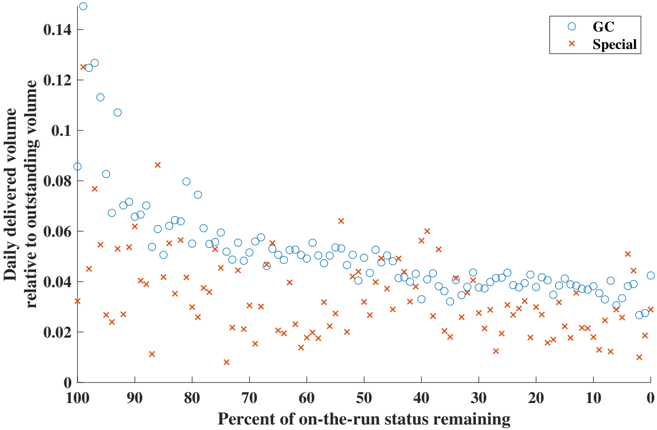

Figure: **On-the-run status remaining**

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# Appendix: CTP spread

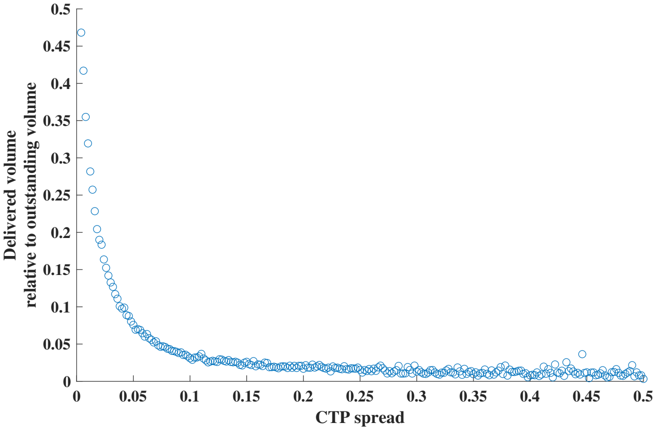

Figure: **CTP spread**

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# Appendix: Repo specialness

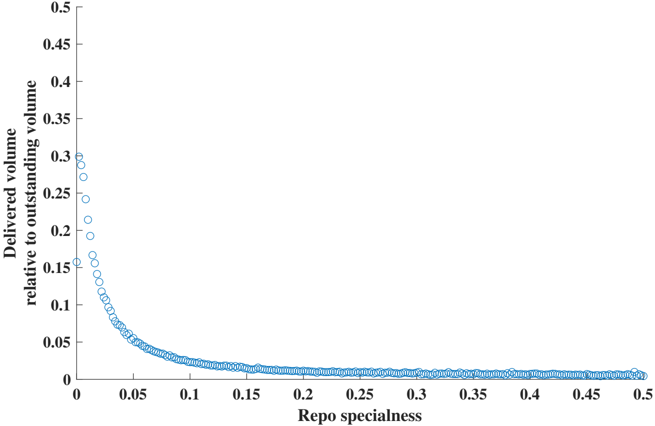

Figure: **Repo specialness**

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# Appendix: CTP spread around quarter- and year-ends

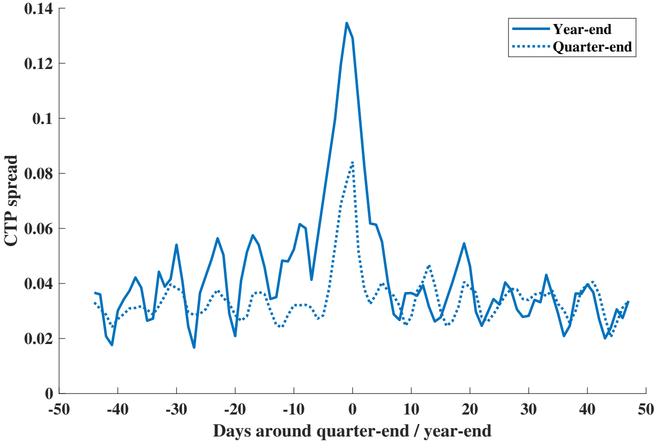

Figure: **CTP spread around quarter- and year-ends**

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# Appendix: Haircut

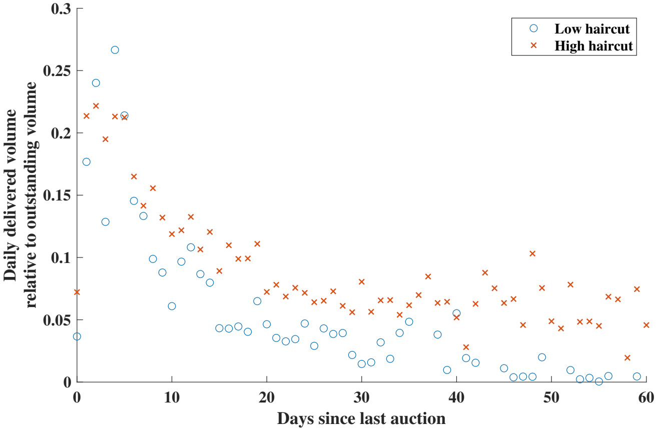

Figure: **Haircut**

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# Repo deliveries and repo specialness

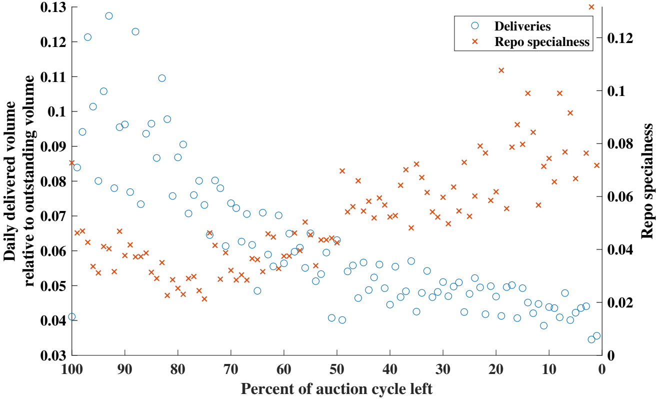

Figure: **Repo deliveries and repo specialness**

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# Appendix: High and low CTP spread

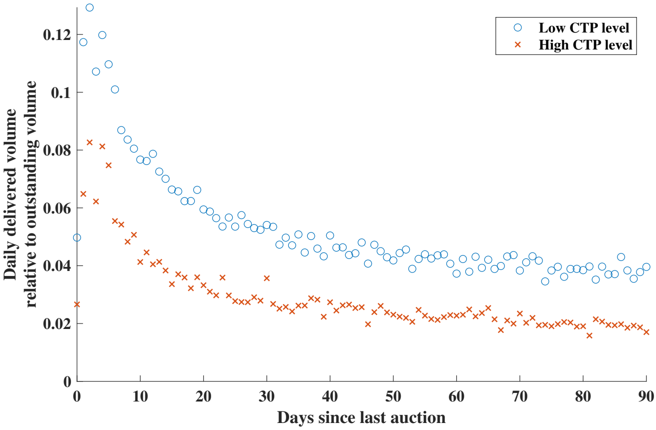

Figure: **High and low CTP spread**

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# Appendix: High and low interest rates

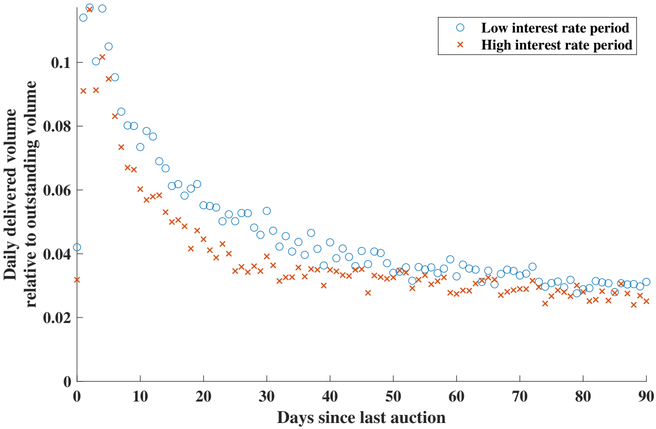

Figure: **High and low interest rates**

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# Detailed empirical results

Table: Collateral availability and opportunity cost

| | Delivery volume | Delivery volume | Delivery volume | Delivery volume | Delivery volume |
|---|---|---|---|---|---|
| Auction size | 0.026 | 0.035* | 0.029 | 0.027 | 0.041** |
| | (1.483) | (1.864) | (1.601) | (1.539) | (2.116) |
| Auction size $\cdot D^{Initial}$ | 0.144*** | 0.150*** | 0.144*** | 0.145*** | 0.154*** |
| | (5.081) | (5.247) | (5.062) | (5.104) | (5.818) |
| Time since auction | −0.143*** | −0.140*** | −0.149*** | −0.144*** | −0.182*** |
| | (−3.281) | (−3.121) | (−3.378) | (−3.288) | (−3.818) |
| Time since auction $\cdot D^{Initial}$ | −4.100*** | −4.262*** | −4.112*** | −4.118*** | −4.036*** |
| | (−14.034) | (−14.479) | (−13.919) | (−14.080) | (−12.905) |
| $D^{OnTheRun}$ | 0.708*** | 0.711*** | 0.868*** | 0.790*** | 0.946*** |
| | (9.795) | (9.693) | (9.532) | (9.994) | (7.015) |
| Time since QE eligibility | −0.691*** | −0.718*** | −0.654*** | −0.657*** | −0.244*** |
| | (−9.226) | (−9.475) | (−8.688) | (−8.924) | (−5.731) |
| $D^{CTP}$ | 0.265*** | 0.390*** | 0.245*** | 0.324*** | 0.388*** |
| | (9.409) | (13.321) | (9.210) | (11.815) | (11.717) |
| CTP spread | −0.294*** | | −0.236*** | | |
| | (−15.978) | | (−12.076) | | |
| Repo specialness | | −0.591*** | | | |
| | | (−10.990) | | | |
| $D^{OnTheRun} \cdot$ CTP spread | | | −0.573*** | | |
| | | | (−10.373) | | |
| $D^{HighCTP}$ | | | | −0.227*** | |
| | | | | (−14.026) | |
| $D^{OnTheRun} \cdot D^{HighCTP}$ | | | | 0.237*** | |
| | | | | (3.620) | |
| $D^{HighInterest}$ | | | | | −0.379*** |
| | | | | | (−6.982) |
| $D^{OnTheRun} \cdot D^{HighInterest}$ | | | | | 0.282*** |
| | | | | | (3.351) |
| $N$ | 611,444 | 611,444 | 611,444 | 611,444 | 613,392 |
| $R^2$ | 0.256 | 0.252 | 0.258 | 0.258 | 0.190 |
| FE | Yes | Yes | Yes | Yes | Yes |

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# Aspects of collateral availability

Table: Aspects of collateral availability

| | Baseline | Relative auction size | OTR status | Securities lending | Low demand |
|---|---|---|---|---|---|
| Auction size | 0.026 | 0.173 | 0.035* | 0.032* | 0.011 |
| | (1.483) | (1.337) | (1.763) | (1.797) | (0.412) |
| Auction size $\cdot D^{Initial}$ | 0.144*** | 1.155*** | 0.069*** | 0.139*** | 0.123*** |
| | (5.081) | (5.972) | (2.600) | (4.839) | (3.140) |
| Time since auction | −0.143*** | −0.141*** | −0.108*** | −0.160*** | −0.123** |
| | (−3.281) | (−3.275) | (−2.731) | (−3.573) | (−2.527) |
| Time since auction $\cdot D^{Initial}$ | −4.100*** | −4.106*** | −3.855*** | −4.115*** | −4.160*** |
| | (−14.034) | (−14.157) | (−14.066) | (−14.044) | (−15.510) |
| $D^{OnTheRun}$ | 0.708*** | 0.707*** | | 0.699*** | 0.715*** |
| | (9.795) | (9.804) | | (9.724) | (10.025) |
| On-the-run remaining | | | 0.017*** | | |
| | | | (12.010) | | |
| Time since QE eligibility | −0.691*** | −0.678*** | −0.647*** | −0.650*** | −0.703*** |
| | (−9.226) | (−9.133) | (−9.309) | (−8.052) | (−8.893) |
| $D^{SecuritiesLending}$ | | | | −0.535** | |
| | | | | (−2.573) | |
| $D^{LowDemand}$ | | | | | 0.139*** |
| | | | | | (2.763) |
| $D^{CTP}$ | 0.265*** | 0.264*** | 0.236*** | 0.262*** | 0.274*** |
| | (9.409) | (9.364) | (8.813) | (9.352) | (8.807) |
| CTP spread | −0.294*** | −0.294*** | −0.309*** | −0.293*** | −0.298*** |
| | (−15.978) | (−15.922) | (−15.840) | (−16.192) | (−15.190) |
| $N$ | 611,444 | 611,444 | 611,444 | 611,444 | 539,726 |
| $R^2$ | 0.256 | 0.257 | 0.276 | 0.258 | 0.254 |
| FE | Yes | Yes | Yes | Yes | Yes |

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# Additional tests and robustness

My analysis provides clear and consistent evidence that **collateral availability** and **opportunity cost** explain *collateral choices*.

- I employ additional controls for:
  - (a) bond characteristics bond,
  - (b) CTD bond in the futures market futures CTD,
  - (c) and economic conditions economic variables.
- I perform my analysis in logs log.
- I experiment with FE specifications and SE clustering FE and SE.
- I repeat my analysis in a sample without end of quarter and end of ECB maintenance period days and without outliers without end of period and outlier.
- I confirm my results in a sample with Germany and France other euro area countries.

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# Appendix: Additional controls and analysis in logs

Table: Robustness checks

| | (1) Baseline | (2) Bond controls | (3) Futures CTD | (4) Economic controls | (5) Log |
|---|---|---|---|---|---|
| Auction size | 0.038* | 0.019 | 0.038* | 0.038* | 0.310*** |
| | (1.880) | (1.129) | (1.894) | (1.884) | (4.913) |
| Auction size $\cdot D^{Initial}$ | 0.160*** | 0.212*** | 0.160*** | 0.161*** | 0.494*** |
| | (5.494) | (9.686) | (5.496) | (5.625) | (8.658) |
| Time since auction | −0.018* | −0.012 | −0.018* | −0.019** | −0.050** |
| | (−1.910) | (−1.131) | (−1.907) | (−2.013) | (−2.499) |
| Time since auction $\cdot D^{Initial}$ | −1.716*** | −1.699*** | −1.716*** | −1.705*** | −0.877*** |
| | (−13.905) | (−13.782) | (−13.908) | (−13.491) | (−11.991) |
| $D^{OnTheRun}$ | 0.809*** | 0.834*** | 0.808*** | 0.795*** | 0.533*** |
| | (10.959) | (12.328) | (10.959) | (11.039) | (9.078) |
| Time since QE eligibility | −0.455*** | −0.428*** | −0.457*** | −0.431*** | −0.357*** |
| | (−9.473) | (−8.873) | (−9.525) | (−9.236) | (−7.041) |
| $D^{CTP}$ | 0.387*** | 0.385*** | 0.388*** | 0.377*** | 0.301*** |
| | (12.704) | (12.592) | (12.707) | (12.234) | (16.179) |
| CTP spread | −0.876*** | −0.809*** | −0.876*** | −0.886*** | −1.570*** |
| | (−8.761) | (−8.367) | (−8.745) | (−9.243) | (−10.788) |
| Bid-to-cover ratio | No | No | No | No | No |
| Bond bid-ask spread | No | Yes | No | No | No |
| Bond tenor | No | Yes | No | No | No |
| Futures CTD | No | No | Yes | No | No |
| Debt-to-GDP | No | No | No | Yes | No |
| CDS | No | No | No | Yes | No |
| QE purchases | No | No | No | Yes | No |
| $N$ | 613,534 | 608,272 | 613,534 | 615,284 | 613,534 |
| $R^2$ | 0.248 | 0.258 | 0.248 | 0.226 | 0.251 |
| FE | Yes | Yes | Yes | Yes | Yes |
| Constant | Yes | Yes | Yes | Yes | Yes |

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# Appendix: FE specifications and SE clustering

Table: Variations in the fixed effect specifications and standard error clustering

| | (1) Baseline Delivery volume | (2) Delivery volume | (3) Delivery volume | (4) Delivery volume | (5) Delivery volume | (6) Delivery volume |
|---|---|---|---|---|---|---|
| Auction size | 0.038* | 0.036*** | 0.033*** | -0.014 | 0.011 | 0.016 |
| | (1.880) | (5.895) | (6.966) | (-0.263) | (0.477) | (0.841) |
| Auction size $\cdot D^{Initial}$ | 0.160*** | 0.138*** | 0.134*** | 0.336*** | 0.348*** | 0.356*** |
| | (5.494) | (9.037) | (11.157) | (5.863) | (15.054) | (16.325) |
| Time since auction | −0.018* | −0.030*** | −0.029*** | 0.001 | −0.016*** | −0.019*** |
| | (−1.910) | (−12.577) | (−16.446) | (0.094) | (−3.980) | (−4.677) |
| Time since auction $\cdot D^{Initial}$ | −1.716*** | −1.555*** | −1.433*** | −1.620*** | −1.631*** | −1.572*** |
| | (−13.905) | (−19.168) | (−22.659) | (−9.692) | (−18.510) | (−19.780) |
| $D^{OnTheRun}$ | 0.809*** | 0.911*** | 0.905*** | 0.844** | 0.838*** | 0.839*** |
| | (10.959) | (34.683) | (43.478) | (3.392) | (25.677) | (30.229) |
| Time since QE eligibility | −0.455*** | −0.038*** | −0.033*** | −0.118 | −0.037*** | −0.018 |
| | (−9.473) | (−5.411) | (−6.355) | (−1.070) | (−3.232) | (−1.350) |
| $D^{CTP}$ | 0.387*** | 0.369*** | 0.365*** | 0.291** | 0.279*** | 0.277*** |
| | (12.704) | (17.278) | (20.757) | (4.472) | (16.869) | (18.879) |
| CTP spread | −0.876*** | −1.307*** | −1.370*** | −0.689*** | −0.738*** | −0.827*** |
| | (−8.761) | (−14.187) | (−20.774) | (−5.208) | (−10.203) | (−14.640) |
| FE | Basket× Month× Term | Basket× Term | Basket | Bond Month× Term | Bond Term | Bond |
| SE-clustering | Bond | Bond× Month | Bond× Month× Term | Basket | Basket× Month | Basket× Month× Term |
| $N$ | 613,534 | 615,480 | 615,508 | 615,183 | 615,504 | 615,508 |
| $R^2$ | 0.248 | 0.183 | 0.145 | 0.279 | 0.257 | 0.226 |
| Constant | Yes | Yes | Yes | Yes | Yes | Yes |

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# Appendix: Results without end of periods and outliers

Table: Results without quarter ends, without end of ECB maintenance periods, and without outliers

| | (1) Baseline | (2) w/o end of quarter | (3) w/o end of ECB maintenance | (4) w/o end of quarter and ECB maintenance | (5) w/o outliers |
|---|---|---|---|---|---|
| Auction size | $0.038^{*}$ | $0.033^{*}$ | $0.037^{*}$ | $0.038^{*}$ | $0.038^{*}$ |
| | (1.880) | (1.706) | (1.859) | (1.898) | (1.876) |
| Auction size $\cdot D^{Initial}$ | $0.160^{***}$ | $0.160^{***}$ | $0.159^{***}$ | $0.161^{***}$ | $0.160^{***}$ |
| | (5.494) | (5.446) | (5.425) | (5.547) | (5.476) |
| Time since auction | $-0.018^{*}$ | $-0.018^{*}$ | $-0.018^{*}$ | $-0.018^{*}$ | $-0.018^{*}$ |
| | $(-1.910)$ | $(-1.955)$ | $(-1.918)$ | $(-1.910)$ | $(-1.918)$ |
| Time since auction $\cdot D^{Initial}$ | $-1.716^{***}$ | $-1.699^{***}$ | $-1.704^{***}$ | $-1.723^{***}$ | $-1.711^{***}$ |
| | $(-13.905)$ | $(-13.687)$ | $(-13.818)$ | $(-13.970)$ | $(-13.881)$ |
| $D^{OnTheRun}$ | $0.809^{***}$ | $0.810^{***}$ | $0.806^{***}$ | $0.812^{***}$ | $0.809^{***}$ |
| | (10.959) | (10.952) | (10.952) | (10.951) | (10.943) |
| Time since QE eligibility | $-0.455^{***}$ | $-0.448^{***}$ | $-0.454^{***}$ | $-0.454^{***}$ | $-0.452^{***}$ |
| | $(-9.473)$ | $(-9.415)$ | $(-9.472)$ | $(-9.451)$ | $(-9.450)$ |
| $D^{CTP}$ | $0.387^{***}$ | $0.342^{***}$ | $0.385^{***}$ | $0.387^{***}$ | $0.384^{***}$ |
| | (12.704) | (11.556) | (12.649) | (12.617) | (12.564) |
| CTP spread | $-0.876^{***}$ | $-2.196^{***}$ | $-0.895^{***}$ | $-0.873^{***}$ | $-0.891^{***}$ |
| | $(-8.761)$ | $(-14.018)$ | $(-8.644)$ | $(-8.758)$ | $(-8.629)$ |
| $N$ | 613,534 | 607,388 | 604,739 | 592,377 | 583,578 |
| $R^2$ | 0.248 | 0.250 | 0.248 | 0.249 | 0.249 |
| FE | Yes | Yes | Yes | Yes | Yes |
| Constant | Yes | Yes | Yes | Yes | Yes |

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# Other euro area countries

Table: Germany and France

| | (1) Delivery volume | (2) Delivery volume | (3) Delivery volume | (4) Delivery volume | (5) Delivery volume | (6) Delivery volume |
|---|---|---|---|---|---|---|
| Auction size | 0.002 | −0.004 | 0.014 | 0.002 | 0.003 | 0.003 |
| | (0.299) | (−0.478) | (1.369) | (0.302) | (0.319) | (0.350) |
| Auction size $\cdot D^{Initial}$ | 0.238*** | 0.170*** | 0.285*** | 0.238*** | 0.239*** | 0.239*** |
| | (4.296) | (3.226) | (5.035) | (4.296) | (4.299) | (4.309) |
| Time since auction | −0.005 | −0.008* | −0.015** | −0.005 | −0.005 | −0.005 |
| | (−1.259) | (−1.792) | (−2.180) | (−1.257) | (−1.247) | (−1.181) |
| Time since auction $\cdot D^{Initial}$ | −0.062*** | −0.043** | −0.078*** | −0.062*** | −0.062*** | −0.062*** |
| | (−3.285) | (−2.511) | (−3.879) | (−3.285) | (−3.280) | (−3.264) |
| $D^{OnTheRun}$ | 0.287*** | | | 0.287*** | 0.288*** | 0.291*** |
| | (5.908) | | | (5.836) | (5.846) | (5.894) |
| On-the-run remaining | | 0.008*** | | | | |
| | | (5.547) | | | | |
| $D^{CTP}$ | | | 0.045 | 0.002 | −0.008 | −0.012 |
| | | | (0.717) | (0.047) | (−0.153) | (−0.238) |
| CTP spread | | | | | −0.266* | |
| | | | | | (−1.685) | |
| Repo specialness | | | | | | −0.386*** |
| | | | | | | (−2.798) |
| $N$ | 2,978 | 2,978 | 2,978 | 2,978 | 2,978 | 2,978 |
| $R^2$ | 0.268 | 0.289 | 0.238 | 0.268 | 0.268 | 0.270 |
| FE | Yes | Yes | Yes | Yes | Yes | Yes |
| Constant | Yes | Yes | Yes | Yes | Yes | Yes |

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# Appendix: Portfolio weights

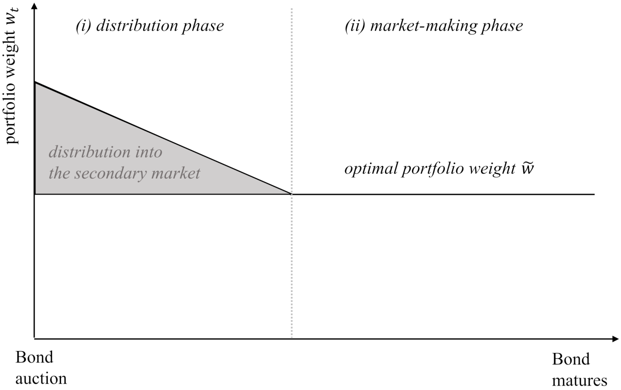

Figure: **Illustration of optimal time-dependent portfolio weight**

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# Appendix: Delivery volume and buy-and-hold investor share

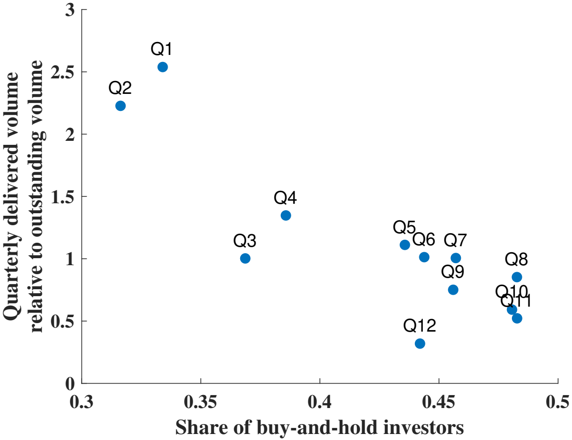

Figure: **Delivery volume and buy-and-hold investor share**

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# Appendix: Extending Stoll (1978)

## My framework builds on Stoll (1978).

- The dealer enters the period with wealth $W_0$. His optimal portfolio choice involves investing a share $k$ into the optimal portfolio (yielding a return $\tilde{R}_e$) and the remaining part of his wealth, i.e., $(1-k)W_0$, as a risk-free investment (yielding $\tilde{r}_f$).
- Over time, the dealer participates in government bond auctions; based on the allotments, the dealer holds an additional **trading portfolio** in on-the-run bonds.
- The dealer finances and rebalances the trading portfolio via the repo market.
- Model is based on a one-period setting during which one trade occurs. The dealer maximizes his **expected utility**, i.e., the expected utility of the terminal wealth of the initial portfolio must be the same as the expected utility after the new trade.

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# Appendix: Model derivation

The optimization condition reads as:

$$EU(\tilde{W}^*) = EU(\tilde{W}). \tag{9}$$

The dealer's end-of-period, terminal wealth from the initial portfolio (comprised of the optimal portfolio, the risk-free investment, and the on-the-run bonds in the trading portfolio) without any trade occurring reads as follows:

$$\tilde{W}^* = W_0[1 + \underbrace{k\tilde{R}_e}_{\substack{\textit{return}\\ \textit{optimal}\\ \textit{portfolio}}} + \underbrace{(1-k)r_f}_{\substack{\textit{return}\\ \textit{risk-free}\\ \textit{investment}}} + \underbrace{\frac{Q_{OTR}}{W_0}(\tilde{R}_{OTR} - OC_i)}_{\substack{\textit{return}\\ \textit{trading}\\ \textit{portfolio}}} - \underbrace{\frac{Q_{OTR}}{W_0}R_F}_{\substack{\textit{financing}\\ \textit{cost}}}]. \tag{10}$$

The dealer's end-of-period, terminal wealth of the new portfolio after a trade (comprised of the initial portfolio, the change in the trading portfolio, and the financing cost of the new trade) reads as follows:

$$\tilde{W} = W_0(1 + \underbrace{\tilde{R}^*}_{\substack{\textit{return}\\ \textit{initial}\\ \textit{portfolio}}}) + \underbrace{Q_i(1 + \tilde{R}_{OTR} - OC_i)}_{\substack{\textit{change}\\ \textit{return}}} - \underbrace{(Q_i - C_i)(1 + R_F)}_{\substack{\textit{change}\\ \textit{financing}\\ \textit{cost}}}. \tag{11}$$

# Appendix: Model derivation

I assume that the dealer is subject to an exponential utility function with constant absolute risk aversion (CARA) of the following form:

$$U(W) = -e^{-aW}, \tag{12}$$

in which $a$ denotes the coefficient of absolute risk aversion.[2] Under the assumption that $W$ is normally distributed with $\sim \mathcal{N}(\mu, \sigma^2)$, we know that:

$$EU(W) = E(W) - \frac{1}{2}a\text{Var}(W). \tag{13}$$

Thus, from Equation (5) follows:

$$E(\tilde{W}^*) - \frac{1}{2}a\text{Var}(\tilde{W}^*) = E(\tilde{W}) - \frac{1}{2}a\text{Var}(\tilde{W}). \tag{14}$$

---

[2] The Arrow–Pratt measure of relative risk aversion $z$ is defined as $z = a \cdot W_0$.

# Appendix: Model derivation

$$\underbrace{E(\tilde{W})}_{(i)} - \underbrace{E(\tilde{W}^*)}_{(ii)} = \frac{1}{2}a[\underbrace{\text{Var}(\tilde{W})}_{(iii)} - \underbrace{\text{Var}(\tilde{W}^*)}_{(iv)}]. \tag{15}$$

Part (i):

$$E(\tilde{W}) = E(W_0(1+\tilde{R}^*)) + E(Q_i(1+\tilde{R}_{OTR} - OC_i)) - (Q_i - C_i)(1+R_F). \tag{16}$$

Part (ii):

$$E(\tilde{W}^*) = E(W_0(1+\tilde{R}^*)). \tag{17}$$

The left hand side of (i)-(ii) simplifies to:

$$E(\tilde{W}) - E(\tilde{W}^*) = Q_i(E(\tilde{R}_{OTR}) - OC_i - R_F) + C_i(1+R_F). \tag{18}$$

# Appendix: Model derivation

$$\underbrace{E(\tilde{W})}_{(i)} - \underbrace{E(\tilde{W}^*)}_{(ii)} = \frac{1}{2}a[\underbrace{\text{Var}(\tilde{W})}_{(iii)} - \underbrace{\text{Var}(\tilde{W}^*)}_{(iv)}]. \tag{15}$$

Part (iii):

$$\text{Var}(\tilde{W}) = \text{Var}(W_0(1+\tilde{R}^*) + Q_i(1+\tilde{R}_{OTR} - OC_i))^3 \tag{19}$$

$$\text{Var}(\tilde{W}) = W_0^2\text{Var}(\tilde{R}^*) + Q_i^2\text{Var}(\tilde{R}_{OTR}) + 2W_0Q_i\text{Cov}(\tilde{R}^*, \tilde{R}_{OTR}). \tag{20}$$

Part (iv):

$$\text{Var}(\tilde{W}^*) = W_0^2\text{Var}(\tilde{R}^*). \tag{21}$$

The right hand side of (iii)-(iv) simplifies to:

$$\text{Var}(\tilde{W}) - \text{Var}(\tilde{W}^*) = Q_i^2\text{Var}(\tilde{R}_{OTR}) + 2W_0Q_i\underbrace{\text{Cov}(\tilde{R}^*, \tilde{R}_{OTR})}_{(v)}. \tag{22}$$

---

[3] Since $R_F$ is nonstochastic, the term $(Q_i - C_i)(1 + R_F)$ drops from the variance equation.

# Appendix: Model derivation

$$\text{Var}(\tilde{W}) - \text{Var}(\tilde{W}^*) = Q_i^2 \text{Var}(\tilde{R}_{OTR}) + 2W_0 Q_i \underbrace{\text{Cov}(\tilde{R}^*, \tilde{R}_{OTR})}_{(v)}. \tag{22}$$

Part (v):

$$\text{Cov}(\tilde{R}^*, \tilde{R}_{OTR}) = \text{Cov}(k\tilde{R}_e + \frac{Q_{OTR}}{W_0}(\tilde{R}_{OTR} - OC_i) + (1 - k - \frac{Q_{OTR}}{W_0})R_F, \tilde{R}_{OTR}) \tag{23}$$

$$\text{Cov}(\tilde{R}^*, \tilde{R}_{OTR}) = k\text{Cov}(\tilde{R}_e, \tilde{R}_{OTR}) + \frac{Q_{OTR}}{W_0}\text{Var}(\tilde{R}_{OTR}). \tag{24}$$

# Appendix: Model derivation

Inserting Equations (18), (22), and (24) into (15):

$$Q_i(E(\tilde{R}_{OTR}) - OC_i - R_F) + C_i(1 + R_F) = \\ \frac{1}{2}a[Q_i^2 \mathrm{Var}(\tilde{R}_{OTR}) + 2W_0 Q_i(k\mathrm{Cov}(\tilde{R}_e, \tilde{R}_{OTR}) + \frac{Q_{OTR}}{W_0}\mathrm{Var}(\tilde{R}_{OTR}))]. \tag{25}$$

# Appendix: Model derivation

We know from the portfolio optimization problem (see Stoll, 1978, p. 1140, footnote 8):[4]

$$E(\tilde{R}_{OTR}) - r_f = (E(\tilde{R}_e) - r_f)\frac{\mathrm{Cov}(\tilde{R}_e, \tilde{R}_{OTR})}{\mathrm{Var}(\tilde{R}_e)} \tag{26}$$

$$k = \frac{E(\tilde{R}_e) - r_f}{aW_0 \mathrm{Var}(\tilde{R}_e)}. \tag{27}$$

This simplifies the decision problem to:

$$C_i = \frac{\frac{1}{2}aQ_i^2 \mathrm{Var}(\tilde{R}_{OTR}) + aQ_i Q_{OTR} \mathrm{Var}(\tilde{R}_{OTR}) + Q_i OC_i(1 - \theta_{Special})}{(1 + R_{GC} - \theta_{Special} OC_i)}. \tag{28}$$

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[4] Equation (26) denotes the classical beta representation of a return in the CAPM, assuming $\beta = \frac{Cov(\tilde{R}_e, \tilde{R}_{OTR})}{\mathrm{Var}(\tilde{R}_e)}$. Equation (27) depicts the optimal fraction invested in the market tangency portfolio, assuming a mean-variance portfolio optimization under negative exponential utility and normally distributed returns.

## Appendix: Bid-ask spread derivation

The relative bid-ask spread is defined as:

$$Rel.BAS_i = \frac{P^A - P^B}{0.5(P^A + P^B)}. \tag{29}$$

In terms of the model variables, note the following: $P^A = P^* + C_i^A$ for the purchase of one unit by the investor from the dealer at the ask ($Q^A = -1$). By this trade, the size of the dealer's trading portfolio decreases by one bond. And $P^B = P^* - C_i^B$ for the sale of one unit from the investor to the dealer at the bid ($Q^B = 1$). By this trade, the size of the dealer's trading portfolio increases by one bond.This leads to

$$Rel.BAS_i = \frac{C_i^A + C_i^B}{0.5(2P^* + C_i^A - C_i^B)}. \tag{30}$$

# Appendix: Bid-ask spread derivation

The cost $C_i$ are defined as

$$C_i^A = \frac{\frac{1}{2} aVar(\tilde{R}_{OTR}) - aQ_{OTR} Var(\tilde{R}_{OTR}) - OC_i(1 - \theta_{Special})}{(1 + R_{GC} - \theta_{Special} OC_i)}, \tag{31}$$

$$C_i^B = \frac{\frac{1}{2} aVar(\tilde{R}_{OTR}) + aQ_{OTR} Var(\tilde{R}_{OTR}) + OC_i(1 - \theta_{Special})}{(1 + R_{GC} - \theta_{Special} OC_i)}. \tag{32}$$

which leads to

$$C_i^A + C_i^B = \frac{aVar(\tilde{R}_{OTR})}{(1 + R_{GC} - \theta_{Special} OC_i)}, \tag{33}$$

and

$$C_i^A - C_i^B = \frac{-2aQ_{OTR} Var(\tilde{R}_{OTR}) - 2OC_i(1 - \theta_{Special})}{(1 + R_{GC} - \theta_{Special} OC_i)}. \tag{34}$$

# Appendix: Bid-ask spread derivation

Inserting Equations (33) and (34) into (30) leads to the following specification of the relative bid-ask spread:[5]

$$Rel.BAS_i = \frac{aVar(\tilde{R}_{OTR})}{P*(1 + R_{GC} - \theta_{Special}OC_i) - aQ_{OTR}Var(\tilde{R}_{OTR}) - OC_i(1 - \theta_{Special})}. \tag{35}$$

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[5] Note, that this derivation is based on the assumption that both quantities traded are equal to one unit. It is possible to include different market depths on the two sides ($|Q^A| \gtrless |Q^B|$) for a more general result, but that derivation does not simplify.

# Appendix: Bid-ask spread derivation

We observe that the relative bid-ask spread increases in the total size of the trading portfolio and in the opportunity cost of the bond:

$$\frac{\partial Rel.Bas_i}{\partial Q_{OTR}} > 0. \tag{36}$$

$$\frac{\partial Rel.Bas_i}{\partial OC_i} > 0. \tag{37}$$

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