Segmented Arbitrage

Internet Appendix

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September 2022

Abstract

In this appendix, we: (i) describe the construction of all arbitrage trades and plot each individual time series, (ii) provide suggestive evidence that unsecured debt is likely the marginal source of financing for equity spot-futures arbitrage, and (iii) present first-stage results for our instrument for flows into Fidelity.

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A.1 Arbitrage Definitions

In Appendix A.1, we provide definitions, data sources, and references for each arbitrage spread. The arbitrage spreads span equity, corporate bond, FX, and Treasury markets. For the U.S. equity market, we estimate spreads from spot-futures and put-call parity no-arbitrage conditions. For the corporate bond market, we estimate the CDS-bond spread. For FX markets, we estimate arbitrage spreads implied by covered interest rate parity. For Treasury markets, we estimate arbitrage spreads from spot-futures, Treasury-swap, and TIPS-Treasury no-arbitrage conditions. Figure A1a and A1b respectively plot average strategy-level spreads at the daily and monthly frequencies.

A.1.1 FX CIP Spread

For the FX market, we estimate deviations from covered interest rate parity (CIP). A CIP deviation is a spread between a cash riskless rate and a synthetic riskless rate. The synthetic rate is local currency borrowing swapped into a foreign denominated rate using cross-currency derivatives. With frictionless arbitrage, the cash riskless rate should be equivalent to the synthetic riskless rate. Du et al. (2018) document large arbitrage spreads among G10 currencies against the USD that persisted after the 2008-09 financial crisis. The CIP deviation at time t for currency c against the USD may be expressed as:

$$\mathrm{CIP}^c_{t,\tau} \equiv y^{\$}_{t,\tau} - (y^c_{t,\tau} - \rho^c_{t,\tau}). \tag{A.1}$$

where τ is tenor, $y^{\$}_{t,\tau}$ is the continuously compounded dollar riskless rate between t and $t+\tau$, and $(y^c_{t,\tau} - \rho^c_{t,\tau})$ is the synthetic dollar risk-free rate, which is comprised of the foreign currency riskless rate $(y^c_{t,\tau})$ and the forward premium $(\rho^c_{t,\tau})$. The forward premium is the annualized difference between the log τ-period forward $(f^c_{t,\tau})$ and spot exchange rates (s^c_t),

both expressed in units of foreign currency per US dollar:

$$\rho^c_{t,\tau} \equiv \frac{1}{\tau}(f^c_{t,\tau} - s^c_t). \tag{A.2}$$

The relevant data is available through Bloomberg. Following Rime et al. (2017) and to be consistent with other arbitrage spreads, we use OIS as the benchmark risk-free rate. We use mid-prices for spot and forward exchange rates from Bloomberg. We use 3-month tenors to avoid the impact of quarter-end effects on measured correlations. Figure A2a plots daily raw CIP spreads for each currency. When the CIP arbitrage spread is negative, the synthetic dollar funding rate is greater than the OIS dollar risk-free rate.

A.1.2 Equity Box Spread

Put-call parity is a no-arbitrage condition relating the difference between the price of European put and call options. For time t, tenor τ, and strike price K_i, let $p_{i,t,\tau}$ denote the price of a put option and $c_{i,t,\tau}$ denote the price of call option. Put-call parity states the difference between two equals the discounted strike price K_i and spot price (s_t) and an adjustment for any dividend cash flows ($\mathcal{C}_{t,\tau}$):

$$p_{i,t,\tau} - c_{i,t,\tau} = (\mathcal{C}_{t,\tau} - s_t) + \exp(-r^f_{t,\tau}\tau)K_i, \tag{A.3}$$

where $r^f_{t,\tau}$ is the implied riskless rate from the option pair. van Binsbergen et al. (2019) compute the $r^f_{t,\tau}$ using a cross-section of call and put options via the following regression:

$$p_i - c_i = \alpha + \beta K_i + \epsilon_i \tag{A.4}$$

This cross-sectional regression is estimated over all strikes for each time t and tenor τ, and avoids the need to estimate cash flows $\mathcal{C}_{t,\tau}$. The estimated β can then be used to back out the implied riskless rate. van Binsbergen et al. (2019) estimate minute-by-minute implied

riskless rates from SPX options and then aggregate to the daily level by taking medians.

The equity box arbitrage spread equals the difference between the option implied and maturity-matched OIS riskless rates. We combine estimates from van Binsbergen et al. (2019), which are available on their websites, with OIS rates from Bloomberg. Figure A2b plots daily raw values for 6, 12, and 18 month equity box arbitrage spreads. When the equity box arbitrage spread is positive, the asset implied risk-free rate from put-call parity is greater than the OIS dollar risk-free rate.

A.1.3 Equity Spot-Futures

Following Hazelkorn et al. (2021), we express the no-arbitrage futures price as:

$$F_{t,\tau} = S_t(1 + r^f_{t,\tau}) - \mathbb{E}^Q_t[D_{t,\tau}], \tag{A.5}$$

where $r^f_{t,\tau}$ is the riskless rate and $\mathbb{E}^Q_t[D_{t,\tau}]$ is the risk-neutral expectation of dividends, both from t to $t + \tau$.

The no-arbitrage condition in Equation (A.5) can also be used to infer implied forward rates. To see why, consider two futures contracts with tenors $\tau_1 < \tau_2$ and let $f_t^{\tau_1,\tau_2}$ denote the time-t forward rate for loans between τ_1 and τ_2. Rearranging Equation (A.5) and solving for the implied forward rate yields:

$$1 + f_t^{\tau_1,\tau_2} = \frac{1 + r^f_{t,\tau_2}}{1 + r^f_{t,\tau_1}} = \frac{F_{t,\tau_2} - \mathbb{E}^Q_t[D_{t,\tau_2}]}{F_{t,\tau_1} - \mathbb{E}^Q_t[D_{t,\tau_1}]} \tag{A.6}$$

We construct arbitrage implied forward rates using the nearby and first deferred futures contracts for the S&P 500, Dow Jones, and Nasdaq 100 indices. We construct implied forward rates $f_t^{\tau_1,\tau_2}$ rather than raw riskless rates (i.e., r^f_{t,τ_1}) spot rates because spot markets for the equity indices close at 4pm EST and futures markets close at 4:15pm EST.[1] Because we have

[1] See contract specification for S&P500 index futures from the CME group at URL: https://www.cmegroup.com/trading/equity-index/us-index/sandp-500_contract_specifications.html

only closing prices for both markets, using Equation (A.5) to construct r^f_{t,τ_1} will necessarily introduce measurement error due to the timing mismatch between spot and futures prices. In contrast, implied forward rates in Equation (A.6) rely only on futures prices across different tenors, thereby mitigating any issues with asynchronous closing times. For all three indices, we proxy for expected dividends using realized dividends, an approach that is supported by Hazelkorn et al. (2021). We obtain realized dividends from Bloomberg. We also assume that dividends are paid uniformly between time t and τ. These assumptions have a small impact on the level of implied forward rates, but do not affect their dynamics, which are the focus of our study.

OIS forward rates are a natural benchmark to use when computing arbitrage spreads from implied forward rates $f_t^{\tau_1,\tau_2}$. Ideally, we would obtain OIS forward curves by bootstrapping the OIS swap curve. A computationally simpler alternative is to infer forward rates based on a linearly interpolated OIS swap curve, denoted by $f^{\tau_1,\tau_2}_{LOIS,t}$. The resulting linearly-interpolated OIS forward rate is over 99% correlated with the 3-month OIS swap rate, denoted by OIS^{3M}_t. We use the latter series when computing equity spot-futures arbitrage spreads because the linearly-interpolated OIS forward rate has mechanical discontinuities around futures roll dates. Formally, we define the equity spot-futures arbitrage spread as:

$$ESF_t = f_t^{\tau_1,\tau_2} - OIS^{3M}_t$$

We have confirmed that all of our results are robust to subtracting $f^{\tau_1,\tau_2}_{LOIS,t}$. Again, the main reason is that the benchmark rate used to compute equity spot-futures arbitrage spreads mainly affects their average level, not their correlation with other spreads. Figure A2c plots daily raw arbitrage spreads for the equity spot-futures arbitrage in the three different equity indices. When the equity spot-futures arbitrage spread is positive, the futures implied risk-free rate is greater than the OIS dollar risk-free rate.

A.1.4 Treasury Spot-Futures

The no-arbitrage condition in Equation (A.5) can also be used to infer implied riskless rates from Treasury futures prices. In practice, implementing the analogue of Equation (A.5) for Treasury futures is complicated by the fact that, unlike equity futures, they are settled with physical delivery, as opposed to cash. For a given contract, the futures exchange predetermines the set of eligible deliverable Treasuries and the futures-implied riskless rate is typically computed based on the cheapest-to-deliver security on each date. These issues and other nuances associated with extracting implied riskless rates are discussed in detail by Fleckenstein and Longstaff (2020) and Barth and Kahn (2021). We follow Fleckenstein and Longstaff (2020) and use futures-implied riskless rates that are computed directly by Bloomberg. We do so for futures for 2-year, 5-year, 10-year, 20-year, and 30-year Treasuries. In all cases, we use implied riskless rates from the first deferred futures contract and only include observations with positive trading volume.[2] This means that within a quarter, the tenor of the implied riskless rate starts at six months and declines to three months over the quarter. We do not use the nearby contract because the seller of Treasury futures has several delivery options during the delivery month, and it is well-known that these options confound prices of the nearby contract in the delivery month (Burghardt and Belton, 2005). For these reasons, most volume in the nearby contract is rolled into the first deferred contract by the beginning of the delivery month (Barth and Kahn, 2021). Finally, to compute arbitrage spreads, we subtract a maturity-matched OIS rate from the futures-implied riskless rate.[3] Figure A2d plots the raw arbitrage spreads for the different Treasury futures contracts. When the Treasury spot-futures arbitrage spread is positive, the futures implied risk-free rate is greater than the OIS dollar risk-free rate.

[2]The filter on positive trading volume primarily affects the futures contract for 30-year Treasuries.

[3]Since the Treasury contract we use has an average tenor of 4.5 months, we use the average of 3- and 6-month OIS. Our results are virtual identical if we linearly-interpolate OIS rates to exactly match the remaining tenor of the Treasury contract. However, as discussed above, such linear interpolation introduces mechanical discontinuities around contract roll dates.

A.1.5 Treasury Swap

In an interest rate swap, one counterparty agrees to pay a series of predetermined payments based on the so-called fixed rate (or swap rate) prevailing at the swap's inception. In return, the counterparty receives a series of stochastic floating payments that is determined based on the future realization of a short-term reference rate. For USD-denominated swaps, common reference rates for the floating leg are 3-month LIBOR (LIBOR swaps), the effective Federal Funds rate (overnight index swaps, or OIS), and more recently, the Secured Overnight Financing Rate (SOFR swaps). To understand no-arbitrage restrictions for interest rate swaps, consider an OIS with tenor τ that pays a fixed rate of $f_{t,\tau}^{OIS}$ and let OIS_t equal the overnight reference rate. Following common practice, we define the Treasury-swap arbitrage spread ("swap spread") as:

$$SS_{t,\tau} = f_{t,\tau}^{OIS} - Treas_{t,\tau}$$

where $Treas_{t,\tau}$ is the yield of a maturity-matched Treasury. Since the 2008 Global Financial Crisis, it has been well-documented that swap spreads have been negative for several floating reference rates and tenors (Jermann, 2020; Du et al., 2022; Hanson et al., 2022). Negative swap spreads represent an arbitrage because an investor could purchase a Treasury via repo at prevailing secured financing rates (denoted s_t), and simultaneously pay fixed and receive floating in the interest rate swap. This transaction would net the investor:

$$\begin{aligned} Profit &= (Treas_{t,\tau} - s_t) + (OIS_t - f_{t,\tau}^{OIS}) \\ &= \underbrace{(Treas_{t,\tau} - f_{t,\tau}^{OIS})}_{-SS_{t,\tau}} + (OIS_t - s_t). \end{aligned}$$

Here, the first term is positive by assumption and the second term equals the difference between the OIS rate (an unsecured rate) and the overnight secured borrowing rate for Treasuries, s_t. Under the natural assumption that unsecured rates are higher than secured ones in every state of the world, the investor will therefore earn a positive arbitrage profit if

swap spreads are negative. As Hanson et al. (2022) and others have argued, this logic also implies that positive swap spreads are only an arbitrage when the underlying reference rate is the secured overnight borrowing rate (i.e., for SOFR swaps).

The preceding discussion suggests that SOFR swaps are the ideal derivative for our analysis. However, because SOFR swaps began trading only in 2018, we instead focus on OIS and obtain their swap rates from Bloomberg for maturities of 1, 2, 3, 5, 10, 20, and 30 years. We compute swap spreads $SS_{t,\tau}$ for each tenor by subtracting out maturity-matched Treasury yields. We chose OIS over LIBOR swaps to minimize any mechanical variation in swap spreads that is driven by bank credit risk.

Figure A2e plots daily raw arbitrage spreads for swap contracts of different tenors. The 1, 2, 3, 5, 10, 20, and 30-year swap spreads are negative for 65%, 81%, 89%, 97%, 100%, 100%, and 100% of our analysis sample, respectively.

A.1.6 TIPS Treasury

In the market for US sovereign debt, there is a no-arbitrage condition between inflation-swapped Treasury Inflation-Protected Securities (TIPS) and Treasuries. TIPS are US Treasury obligations for which the principal amount (and coupons) are adjusted for the Consumer Price Index (CPI). These inflation adjustments may be undone using an inflation swap, yielding fixed cash flows. The arbitrage spread is the difference in yield between this synthetic nominal Treasury constructed from TIPS and inflation swaps and a nominal Treasury. Define $y_{T,t,\tau}$ to be the Treasury yield, $s_{t,\tau}$ to be the TIPS yield, and $f_{t,\tau}$ to be the fixed inflation swap rate. The TIPS-Treasury spread ($\mathrm{TT}_{t,\tau}$) is

$$\mathrm{TT}_{t,\tau} = (s_{t,\tau} + f_{t,\tau}) - y_{T,t,\tau} \tag{A.7}$$

Following Fleckenstein et al. (2014), we estimate the TIPS-Treasury spread use data from the Treasury and Bloomberg. For our primary sample of analysis (Jan 2010 to Feb 2020), we

have 69 pairs of TIPS and Treasuries, which includes 26 of the 29 TIPS described in Table III of Fleckenstein et al. (2014).[4] For TIPS that mature before April 15th 2013, we have the same paired Treasury as in Table III of Fleckenstein et al. (2014). For TIPS that mature on or after April 15th 2013, we match to different nominal Treasury because we can find a closer match in terms of maturity date among Treasuries issued since the writing of Fleckenstein et al. (2014). An arbitrageur may earn the spread $\mathrm{TT}_{t,\tau}$ by buying TIPS and a series of inflation swaps for each cash flow and selling a Treasury. For a specific example of this trade see Table II of Fleckenstein et al. (2014).

A.1.7 Corporate CDS-Bond Spread

We build arbitrage spreads and implied riskless rates based on the relative pricing of corporate credit default swaps (CDS) and risky bonds. Corporate CDS are essentially an insurance contract against the default of an underlying corporate debt security. The buyer of CDS protection pays a fixed annuity premium (the CDS spread) to the seller for a pre-specified horizon τ. In return, if there is a default event before τ, the seller pays the buyer the difference between the par value of the security and its market value. Duffie (1999) formally shows that the cash flows from purchasing CDS protection on firm i are equivalent to a portfolio that is long a default-free float rate note and short the floating rate debt of firm i. Consequently, the CDS spread should equal the floating rate spread, defined as the spread of par floating rate debt for firm i over the riskless rate. Intuitively, an investor who simultaneously purchases the debt of a risky issuer and CDS protection on that same issuer faces no credit risk, and should therefore earn the riskless rate.

Because most corporate entities do not issue floating rate debt, it common practice to use so-called Z-spreads or asset swap spreads to infer the floating rate spread from the price of fixed rate corporate debt (Choudhry, 2018). Let $FR_{i,t,\tau}$ denote the time-t floating rate spread implied by a fixed-rate bond issued by firm i with tenor τ. Motivated by the no-arbitrage

[4] 3 TIPS are excluded because they mature prior to the start of our sample.

logic above, we define the CDS-bond arbitrage spread (or basis) for debt issued by firm i with tenor τ as follows:[5]

$$CB_{i,t,\tau} = CDS_{i,t,\tau} - FR_{i,t,\tau}, \tag{A.8}$$

where $CDS_{i,t,\tau}$ is the maturity-matched CDS spread for firm i. This object can be bootstrapped based on the market values of CDS contracts trading on firm i at each point in time. A negative basis implies that the bond is trading a low price relative to the CDS, and an investor could earn a positive arbitrage profit by going long the bond and purchasing CDS protection.

We build individual bond bases using data from Markit. Markit's bond pricing platform contains daily prices for a wide range of globally issued bonds, with pricing information sourced from market-makers, TRACE, and FINRA.[6] For each bond issue, Markit also computes the Z-spread and the implied par asset-swap spread. Z-spreads are more populated in Markit and so we use them to proxy for $FR_{i,t,\tau}$ in Equation (A.8). We use par asset-swap spreads when Z-spreads are not available. In addition, Markit uses daily CDS pricing to bootstrap the CDS spread $CDS_{i,t,\tau}$ associated with the maturity of each bond. When Markit's bootstrapped value is unavailable, we compute it ourselves by interpolating using cubic spline over constant-maturity CDS spreads that are also sourced from Markit. For each bond, we also compute a maturity-matched Treasury yield (denoted $y_{t,\tau}$) using a cubic spline interpolation and define the arbitrage-implied riskless rate as $rf^{CDS}_{i,t,\tau} = y_{t,\tau} - CB_{i,t,\tau}$. Finally, we create aggregate indices by taking the equal-weighted average of individual bond bases $CB_{i,t,\tau}$ and implied riskless rates $rf^{CDS}_{i,t,\tau}$ for both investment grade (IG) and high-yield rated firms (HY).

We apply several filters to the Markit bond database, mainly to ensure we only use liquid and reliable bond prices in our IG and HY indices. Specifically, we: (i) include only senior unsecured debt that is issued in USD by U.S. firms and has a non-missing ISIN; (ii) include

[5] There are several alternative methodologies for defining the CDS-bond basis that account for the fact that most corporate debt is fixed, not floating rate (see Bai and Collin-Dufresne, 2019 for a complete discussion). Z-spreads and asset swap spreads are readily available to us from our data provider (Markit) and so we use them for simplicity.

[6] See the Markit pricing brochure for more information.

fixed rate bonds with maturity between 1 and 10 years; (iii) include only bonds with an outstanding principle of at least $100,000, where principal values are sourced from Mergent and matched to Markit using ISINs; (iv) exclude putable and convertible bonds; and (v) exclude bonds whose composite price is less than fifty cents on the dollar. To further ensure we use reliable bond pricing, in a given month we only include bonds whose ISINs are included in the WRDS Bond Return dataset. The WRDS Bond Return data is based on a cleaned set of bond transactions sourced from TRACE and TRACE enhanced.

Figure A2g plots daily raw average arbitrage spreads for investment grade (IG) and high yield (HY) bonds. Over our sample period, the IG CDS-Bond arbitrage index reflects an average of 1,690 bonds per day issued by 358 firms. Over the same period, the HY index reflects an average of 307 bonds per day issued by 108 unique firms.

A.1.8 Synchronicity of Prices

For the computation of each arbitrage spread, we use New York closing prices (5PM Eastern Time) when available. We have synchronously measured arbitrage spreads at New York closing prices for the following trades: CIP, Treasury spot-futures, TIPS-Treasury, and Treasury-swap. For the equity spot-futures trade, the closing price is at 4:15 pm Eastern Time. For the Equity-Box asset implied risk-free rate, van Binsbergen et al. (2019) reports the median of minute-level estimates over the day. All arbitrage spreads are measured from mid-prices of composite quotes by multiple dealers. CDS and asset swaps spreads are based on both transactions and quotes that are aggregated by Markit.

A.1.9 Outliers

For the spot-futures arbitrages, which include CIP, equity spot-futures, and Treasury spot-futures, we correct for 1-day outliers in spreads. If an arbitrage spread increases by 50 percent or more followed by a next day decrease of 50 percent or more (or vice-versa a 50 percent decrease followed by a 50 percent increase), we omit this observed arbitrage spread. To avoid

excessive omissions for arbitrage spreads near zero, we further require a size threshold of 25 bps, such that the 1-day spread spike is at least 12.5 bps. This approach is motivated by the cleaning procedure in Rossi (2014).

A.2 Additional Results and Discussion

A.2.1 Marginal Financing of Unsecured Trades

In Section 4.2 (Table 4), we find that the sensitivity of unsecured arbitrage spreads to the TED spread generally exceeds the margin requirements listed in Table 3. Our interpretation is that the marginal dollar of financing for these trades requires more unsecured funding than on average. We would ideally confirm this interpretation with data on how arbitragers using unsecured strategies (CIP, Box, and Equity spot-futures) finance their trading activity. Because this data is difficult to obtain, we instead present suggestive evidence by comparing the value of equity securities held by dealers to the size of the equity repo market. We calculate the former based on Y-9C regulatory filings by all U.S. bank holding companies, and we calculate the latter based on public data provided by the New York Federal Reserve. Figure A3 plots the two series starting in 2010Q2, which is when equity repo market data first becomes available. The key takeaway is that the U.S. equity repo market does not appear large enough to fully finance the holdings of equities by U.S. bank holding companies. On average, the collateral value in the equity repo market is 41% of the value of equities held by U.S. bank holding companies. Thus, to the extent that U.S. bank holding companies are active in equity spot-futures arbitrage, it seems unlikely that their marginal dollar of arbitrage financing comes from the equity repo market.[7]

[7] The sensitivity of equity spot-futures arbitrages to the TED spread (Section 4.2) and the event study of the JPMorgan London Whale (Section 5.2) both suggest that U.S. dealers are indeed active in equity spot-futures arbitrage.

A.2.2 First-Stage IV for Analysis of Fidelity Flows

In Section 4.3, we illustrate funding segmentation by showing that supply shocks from Fidelity MMFs uniquely impact equity-spot futures arbitrage. We isolate supply shocks using an IV strategy in which we instrument for Fidelity flows using what we call "passive Fidelity flows,"defined as flows to the aggregate MMF sector in month t interacted with Fidelity's share of MMF assets measured at $t-6$. Table A1 shows the first-stage regression results for the IVs reported in columns (4)-(6) of Table 6. The only thing that differs across the columns is the estimation sample. The first column corresponds to the sample used when the outcome variable in the IV regression is the implied riskless rate in the equity-spot futures arbitrage. The second corresponds to the sample used when the outcome is the implied riskless rate in other secured arbitrages (CIP and Box), and the third corresponds the sample using secured arbitrages. In all cases, the sign of the coefficient on passive Fidelity flows is positive as expected and highly significant. Thus, our IV does not suffer from a weak instruments problem.

References

Bai, J. and P. Collin-Dufresne (2019). The cds-bond basis. *Financial Management 48*(2), 417–439. 9

Barth, D. and R. J. Kahn (2021). Hedge funds and the treasury cash-futures disconnect. 5

Burghardt, G. and T. Belton (2005). *The Treasury Bond Basis: An in-Depth Analysis for Hedgers, Speculators, and Arbitrageurs.* McGraw-Hill Library of Investment and Finance. McGraw-Hill Education. 5

Choudhry, M. (2018). *Derivative Instruments and Hedging*, Chapter 2, pp. 120–270. John Wiley and Sons, Ltd. 8

Du, W., B. M. Hébert, and W. Li (2022). Intermediary balance sheets and the treasury yield curve. Technical report, National Bureau of Economic Research. 6

Du, W., A. Tepper, and A. Verdelhan (2018). Deviations from covered interest rate parity. *The Journal of Finance 73*(3), 915–957. 1

Duffie, D. (1999). Credit swap valuation. *Financial Analysts Journal 55*(1), 73–87. 8

Fleckenstein, M. and F. A. Longstaff (2020). Renting balance sheet space: Intermediary balance sheet rental costs and the valuation of derivatives. *The Review of Financial Studies 33*(11), 5051–5091. 5

Fleckenstein, M., F. A. Longstaff, and H. Lustig (2014). The tips-treasury bond puzzle. *the Journal of Finance 69*(5), 2151–2197. 7, 8

Hanson, S. G., A. Malkhozov, and G. Venter (2022). Demand-supply imbalance risk and long-term swap spreads. *SRC Discussion Paper No 118*. 6, 7

Hazelkorn, T., T. Moskowitz, and K. Vasudevan (2021). Beyond basis basics: Liquidity demand and deviations from the law of one price. *The Journal of Finance forthcoming.* 3, 4

Jermann, U. (2020). Negative swap spreads and limited arbitrage. *The Review of Financial Studies 33*(1), 212–238. 6

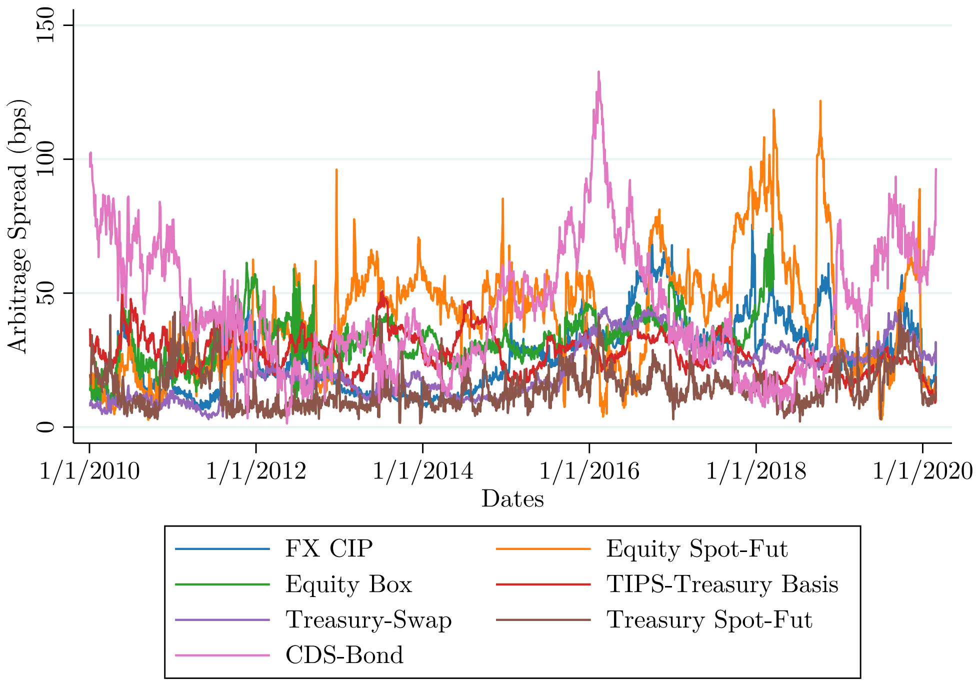
Rime, D., A. Schrimpf, and O. Syrstad (2017). Segmented money markets and covered interest parity arbitrage. 2

Rossi, M. (2014). Realized volatility, liquidity, and corporate yield spreads. *The Quarterly Journal of Finance 4*(01), 1450004. 11

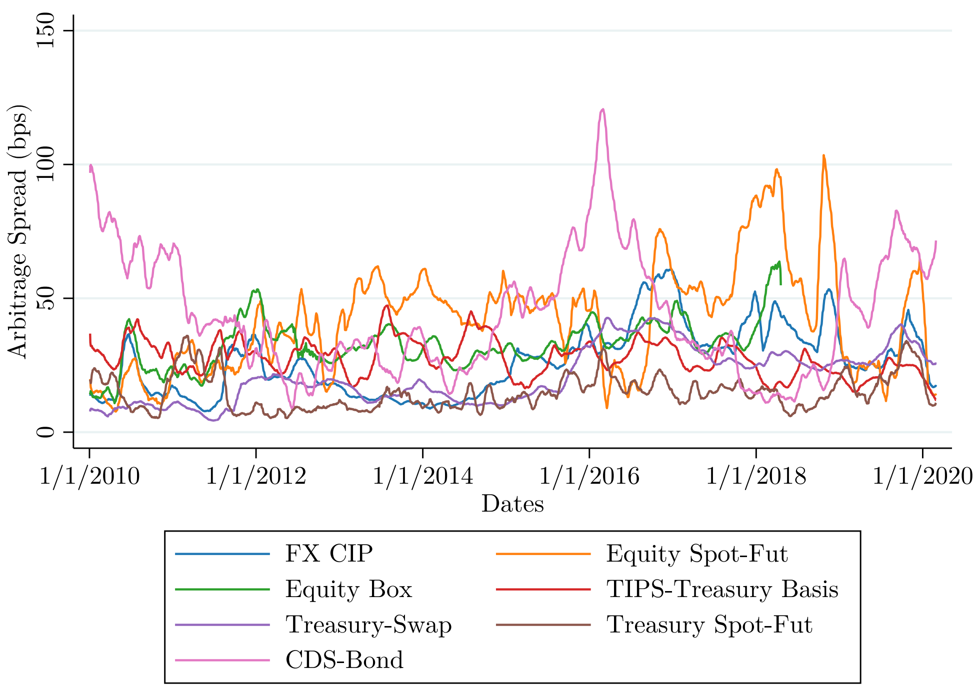
van Binsbergen, J. H., W. F. Diamond, and M. Grotteria (2019). Risk-free interest rates. Technical report, National Bureau of Economic Research. 2, 3, 10

Figure A1: Strategy-Level Average Arbitrage

(a) Daily Frequency



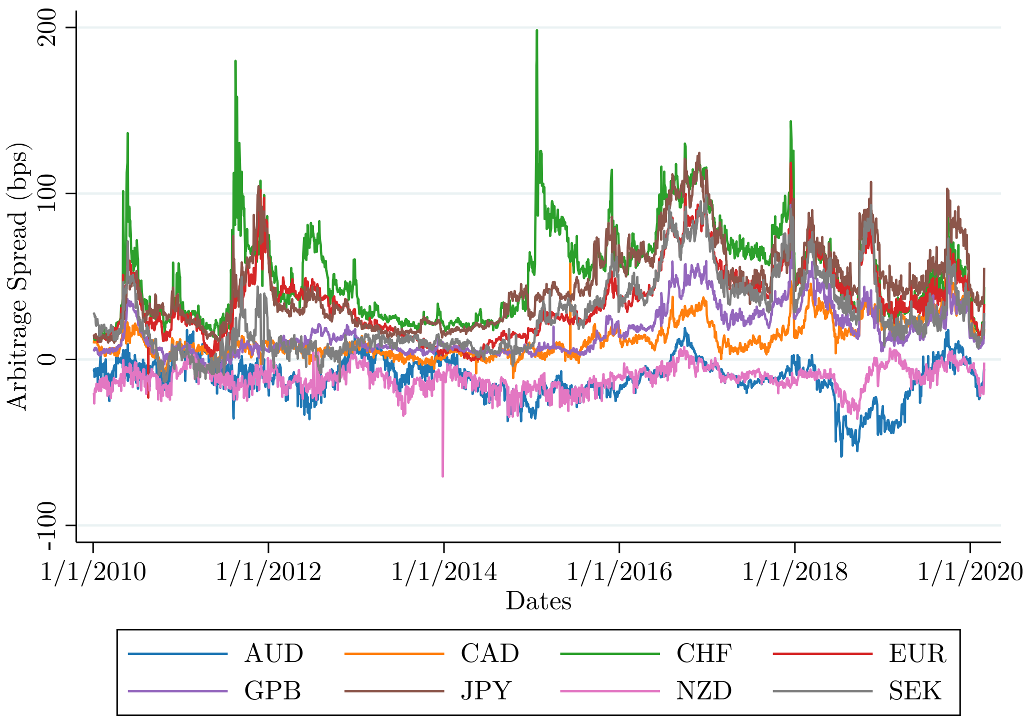
(b) Monthly Moving Average



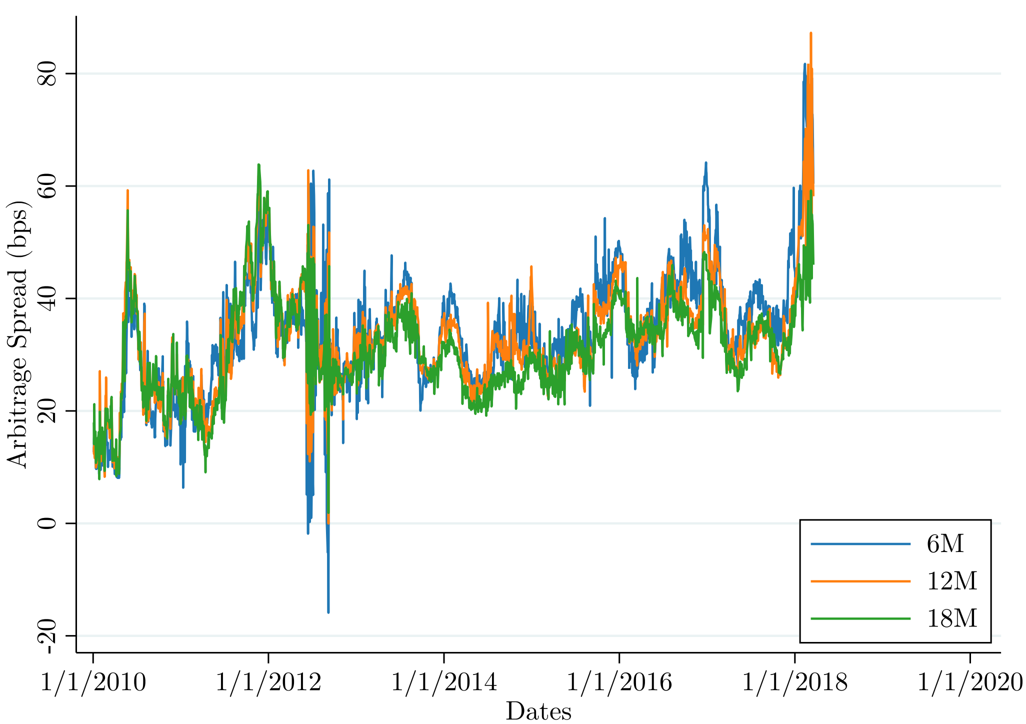
Notes: Panel A shows the average arbitrage spread by strategy at the daily frequency. Panel B plots a monthly (22 trading days) moving average of the daily series for each strategy.

Figure A2: Time-Series of Arbitrage Spreads

(a) CIP

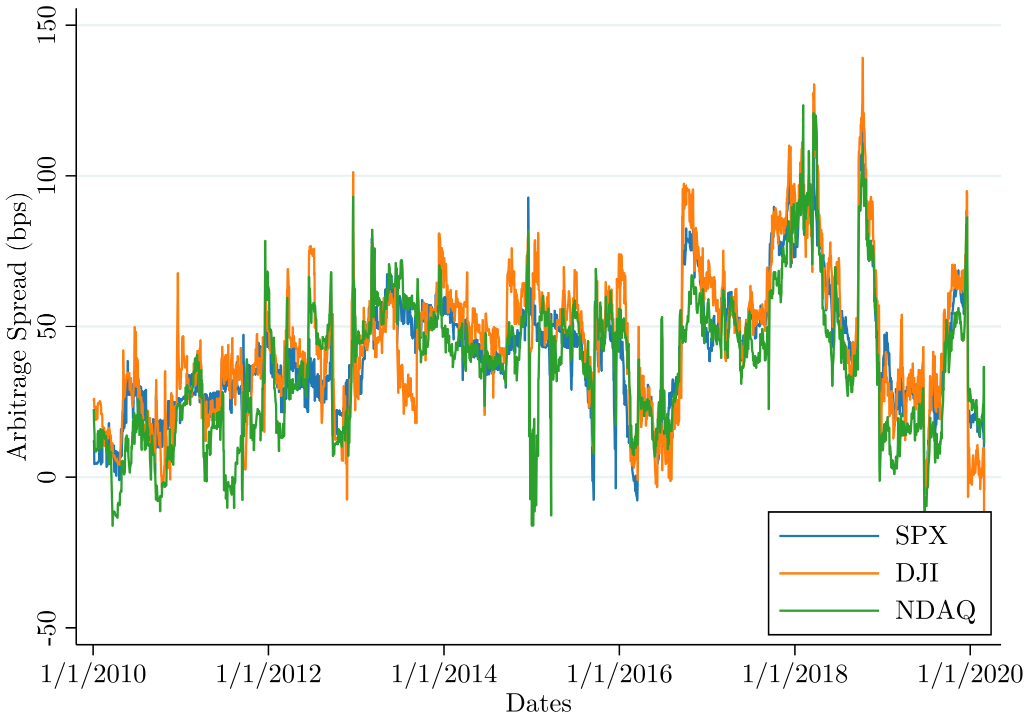


(b) Box Spread

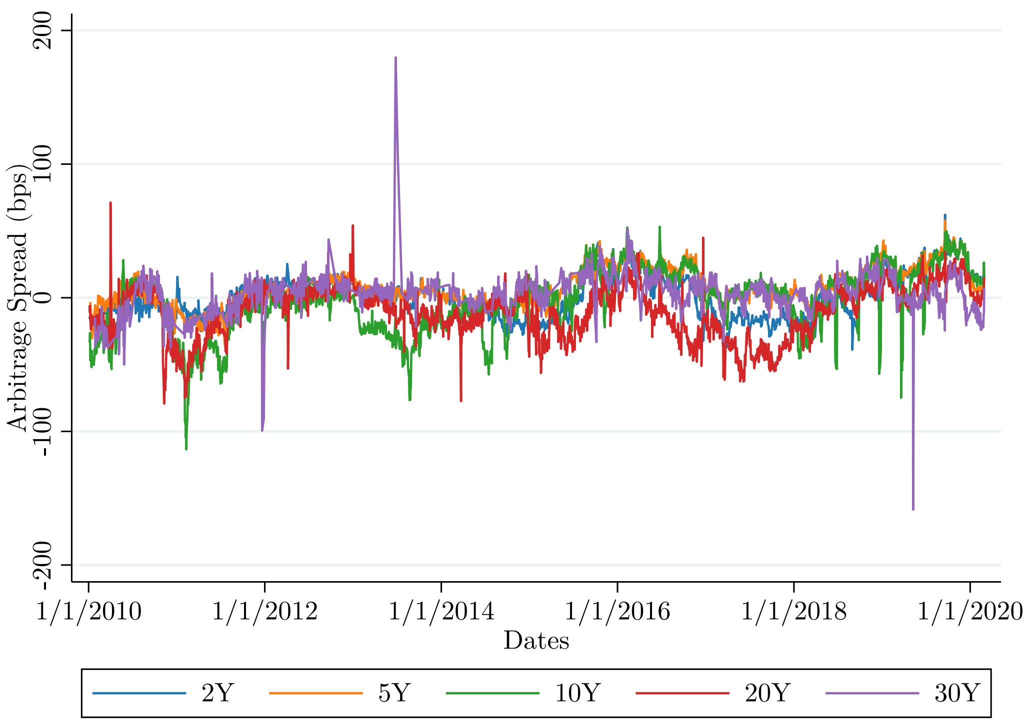


Notes: Each panel shows the daily-time series of individual arbitrage trades for a given strategy.

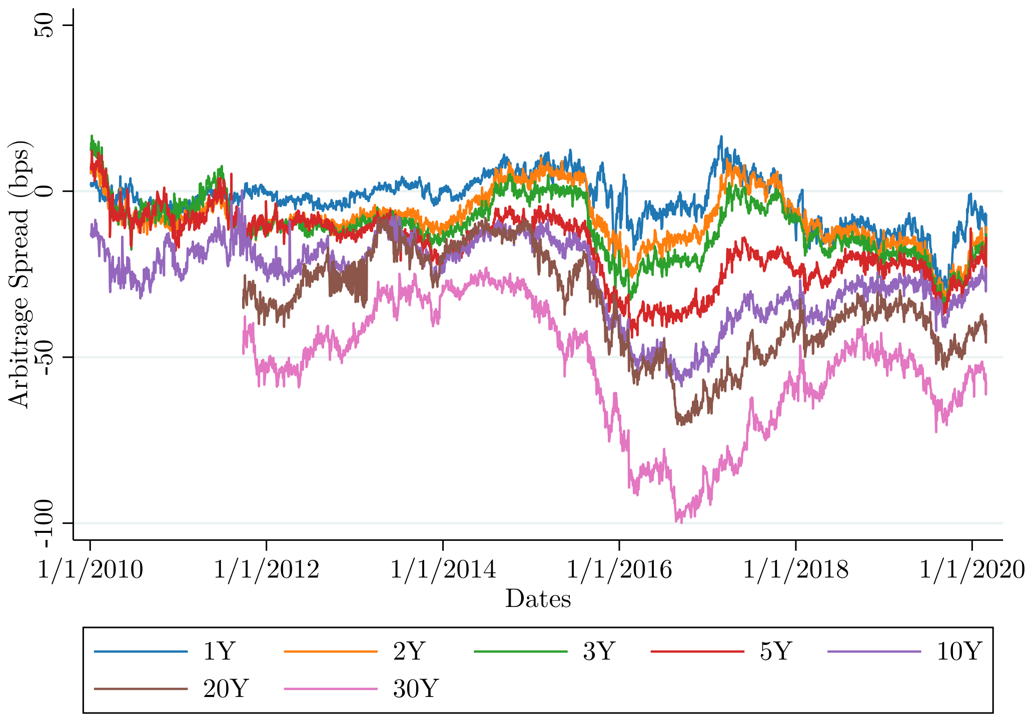
(c) Equity-Spot Futures



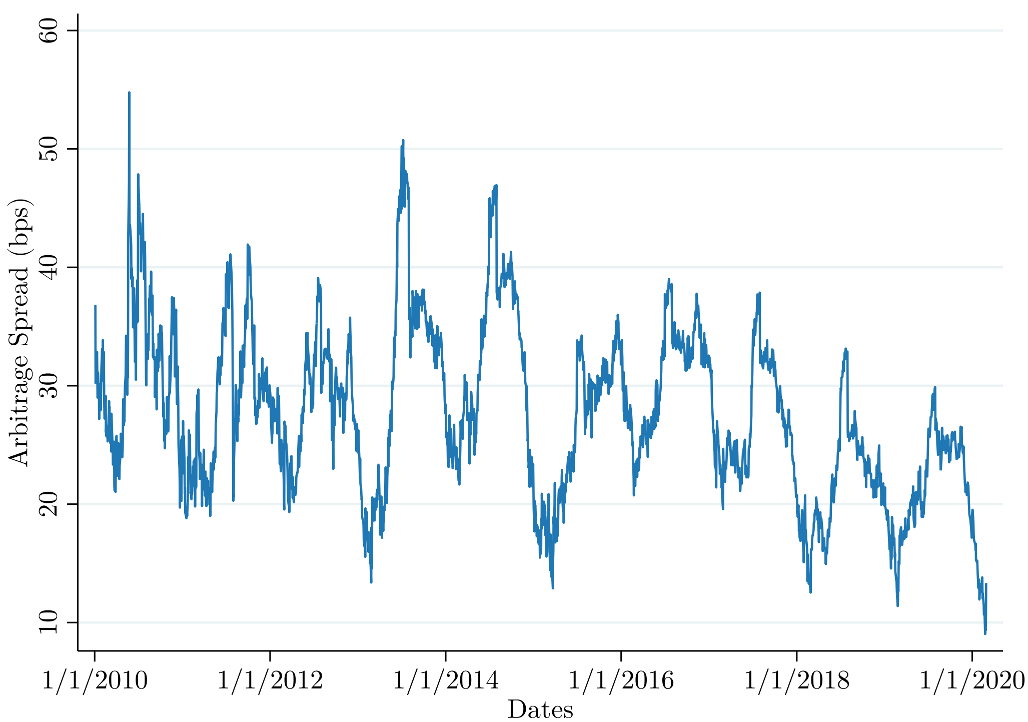
(d) Treasury-Spot Futures



(e) Treasury-Swap



(f) TIPS-Treasury



(g) CDS-Bond Basis (IG)

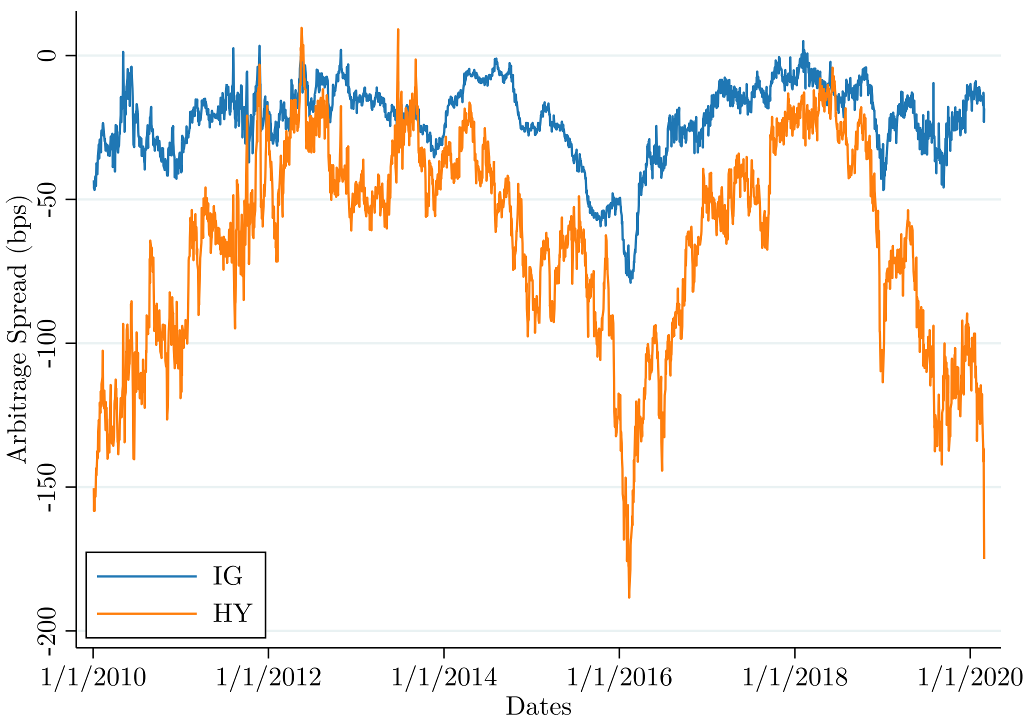
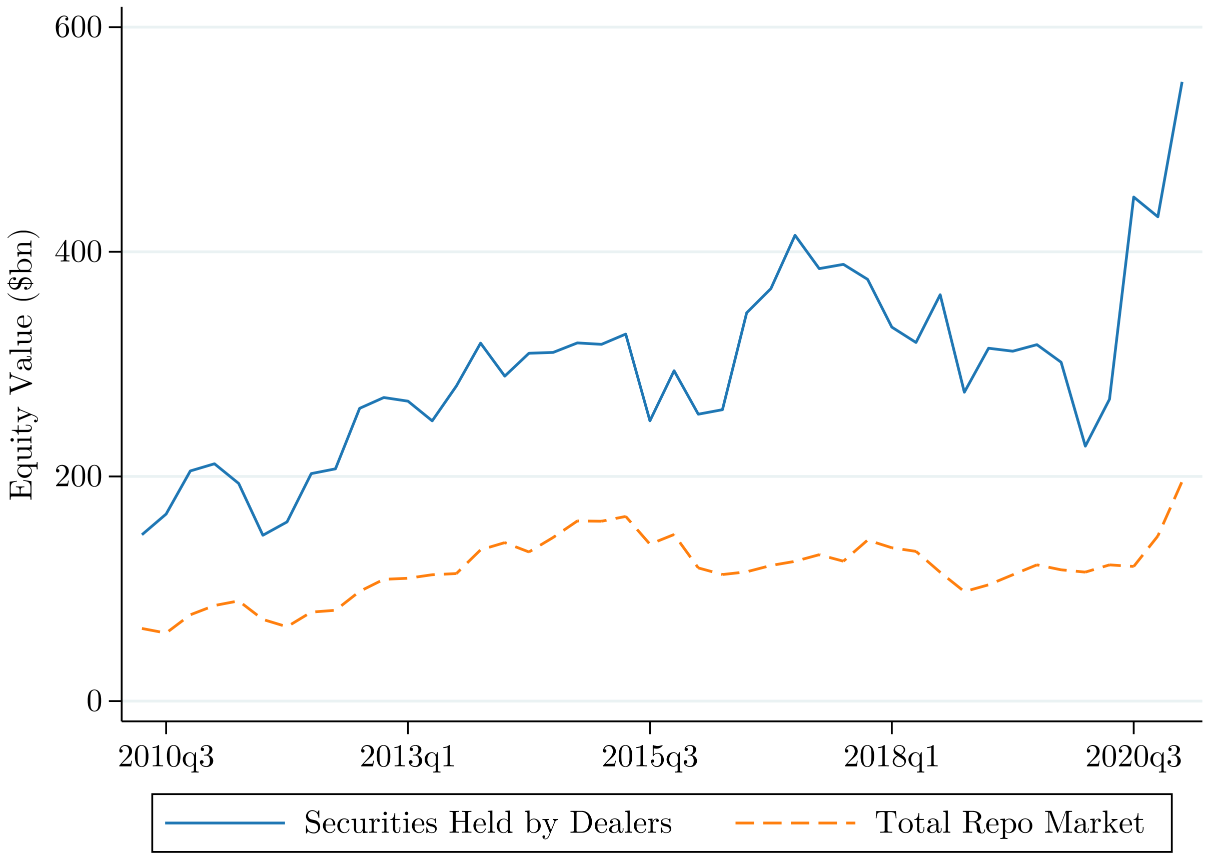


Figure A3: Value of Equity Securities Held by Dealers vs Equity Repo Market



Notes: This figure shows the value of equity securities held by U.S. bank holding companies and the total value of equity collateral in the U.S. equity repo market. The first series is based on Y-9C filings and the second is based on publicly available data from the New York Federal Reserve.

Table A1: Arbitrage-Implied Riskless Rates and Funding Shocks to Fidelity (First-Stage IV)

	Dep Variable: Fidelity Flows		
	(1)	(2)	(3)
	Equity S-F	CIP/Box	Secured
Passive Fidelity Flows	4.26**	4.25**	4.23**
	(10.20)	(12.44)	(16.36)
Δ Treasury	0.04*	0.04**	0.01
	(1.76)	(2.31)	(1.24)
Δ TED	0.06**	0.06**	0.03**
	(3.25)	(3.58)	(2.40)
R^2	0.50	0.50	0.44
N	294	1,033	1,447

Notes: This table presents first-stage IV estimates where flows out of Fidelity money market funds are instrumented using net flows for the entire money market fund sector interacted with Fidelity's share of money market fund assets, lagged by six months (passive Fidelity flows). Additional controls in the regression are the maturity-matched Treasury yield and the change in the maturity-matched TED spread. Define l and m, respectively, as the maturities of the nearest-maturity LIBOR and Treasury for a given trade. The maturity-matched TED spread for the trade is then defined as $LIBOR(l) - Treasury(l)$ and the maturity-matched Treasury yield is defined as $Treasury(m)$. l does not equal m for longer-tenor trades (e.g., 30-year Treasury swap) because the maximum maturity LIBOR rate we observe is one year. Column (1) is the first-stage when outcome variable in the IV regression is equity spot-futures implied riskless rate. Columns (2) and (3) show first-stage estimates for when the outcome variable in the IV regressions are implied riskless rates implied by, respectively, other unsecured trades (CIP and Box) and secured trades. All implied riskless rates are in basis points and flows are in percentage points. t-statistics are reported under point estimates and are based on standard errors clustered by strategy-month.