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Renting Balance Sheet Space: Intermediary Balance Sheet Rental Costs and the Valuation of Derivatives

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A long-standing asset pricing puzzle is that the funding rates in derivatives contracts often differ from those in cash markets. We propose that the cost of renting intermediary balance sheet space may help resolve this puzzle. We study a persistent basis in what is arguably the largest derivatives market, namely, the interest rate futures market. This basis is strongly related to exogenous measures of intermediary balance sheet usage and proxies for the balance sheet costs imposed by debt overhang problems and capital regulation. These results extend to the cash derivatives bases documented in many of the other largest financial markets. (*JEL* G12, G13, G21)

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> Balance sheet space is treated like expensive real estate, available only to positions that can afford to pay rental fees that are now much larger.
>
> Darrell Duffie[1]

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[1] Duffie (2016).

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> Bankers are blaming tensions in the repo world on the increasing cost of renting out their balance sheets.
>
> Izabella Kaminska[2]

What interest rate should be used in the Black-Scholes formula? In theory, the financing rate for derivative contracts in the risk-neutral world should be the interest rate for a riskless bond. In reality, however, one of the long-standing puzzles in derivatives pricing is that the implicit funding rates for derivatives often diverge from actual financing rates in the cash markets. Early studies documenting this phenomenon date back at least 30 years to Brenner and Galai (1986), Ronn and Ronn (1989), and Longstaff (1995), among others. Although framed in various ways, a number of more recent studies also can be viewed as evidence of a similar funding-related basis between actual securities and derivative/synthetic securities. Examples include violations of the covered interest rate parity (CIP) relation (Du, Tepper, and Verdelhan 2018), the corporate bond/credit default swap (CDS) basis (Longstaff, Mithal, and Neis 2005; Duffie 2010; Bai and Collin-Dufresne 2019), and dollar roll specialness in the agency mortgage-backed security market (Song and Zhu 2019).

An important recent literature provides evidence that intermediary balance sheet constraints may play a central role in explaining the pricing of financial assets in the market. Motivated by this literature, we examine whether the reverse is also true: does the cost of renting balance sheet space from financial intermediaries also help explain the mispricing of derivative contracts relative to the underlying securities? This issue is particularly relevant in derivatives markets, because intermediation may require a much more intensive use of balance sheet space. This is because the intermediary must not only hold the underlying security as a hedge but also take the other side of the derivatives transaction and face additional costs and constraints.

At the outset, we emphasize that we are not the first to suggest that intermediary balance sheet issues may help explain asset mispricing. For example, this is a central theme of an important recent paper by Du, Tepper, and Verdelhan (2018), who study the persistent violations of CIP during the post-crisis period.[3] Rather, the primary contribution of our paper is to provide evidence that the results of Du, Tepper, and Verdelhan (2018) simply may be the tip of the iceberg: the cost of renting intermediary balance sheet space may also help explain much larger examples of mispricing in much larger derivatives markets over much longer time periods than has been previously documented in the literature.

To understand the intuition behind how the cost of renting balance sheet space could affect the pricing of derivatives, consider an investor who wants

[2] Kaminska (2016).

[3] See also Gârleanu and Pedersen (2011).

exposure to changes in the value of a security. The investor has two ways of achieving this objective. First, the investor can own the security outright by purchasing it in the cash market and placing it on its own balance sheet. Alternatively, the investor could take a synthetic position in the security using, for example, a total return swap or some other type of derivative contract. To facilitate the transaction, however, an intermediary must place the security—and the derivative contract—on its balance sheet and incur any resultant balance sheet usage costs. In this case, the investor essentially is "renting" the security from an intermediary in the derivatives market. In equilibrium, the implied funding rate the intermediary earns by renting out its balance sheet and taking the other side of the transaction equals the financing rate in the cash market plus the balance sheet usage costs incurred by the intermediary.

Financial intermediaries face a number of potential costs in using their balance sheets to provide intermediation. A number of recent studies focus on the costs imposed by post-crisis capital regulations, such as the Dodd-Frank Act and the supplementary leverage ratio (SLR) and liquidity coverage ratio (LCR) requirements of the Basel III framework. It is important to recognize, however, that capital regulation is not the only source of balance sheet usage costs. Duffie (2018) states: "… the increased reluctance by big banks to use their balance sheets for intermediation is in many cases caused by increased funding costs that have nothing to do with regulatory capital requirements." Recent research by Duffie (2018) and Andersen, Duffie, and Song (2019) emphasizes the role that debt overhang issues may play in imposing balance sheet costs on financial intermediaries. Other examples of balance sheet usage costs include the cost of collateralizing liabilities (Johannes and Sundaresan 2007), the costs of value-at-risk constraints (Adrian and Brunnermeier 2016; Brownlees and Engle 2017), and the cost of funding illiquidity (Brunnermeier and Pedersen 2009).

In exploring the relation between the cost of renting balance sheet space and the pricing of derivatives, it seems appropriate to focus first on the derivatives market that is probably associated with the largest demand for notional balance sheet space, namely, the interest rate futures market. The Bank for International Settlements (BIS) reports that the average daily trading turnover for interest rate futures during 2016 was $5.046 trillion. In contrast, the average daily trading turnover during the same period was $1.859 trillion for interest rate swaps, $0.700 trillion for foreign exchange forward contracts (used in the CIP strategy), and $0.209 trillion for agency TBAs (used to create dollar rolls).[4]

As a specific example, we begin by studying the basis between Treasury notes and Treasury note futures. This basis can be directly observed as the difference between the implicit funding rate in the futures contract (implied repo rate) and the financing rate for Treasury notes (the repo rate). We denote

[4] See https://stats.bis.org/statx/srs/table/d1?p=20164&c=, https://www.bis.org/statistics/d12_1.pdf, https://www.bis.org/statistics/d11_1.pdf, and https://www.sifma.org/resources/research/us-bond-market-trading-volume.

this difference as the funding basis. An important advantage of focusing on the actively traded trillion-dollar Treasury note/Treasury note futures markets is that we can study the effects of balance sheet rental costs on derivative pricing over a much-longer time period ranging from 1991 to 2018.

A number of key results emerge from the analysis. First, consistent with Duffie (2018), the results imply that we must consider other factors besides post-crisis capital regulation in order to fully explain the mispricing of derivatives relative to the underlying securities. In particular, we find a large positive funding basis throughout most of the 1991–2018 sample period. Furthermore, the funding basis is as large during the 1990s as it is during the post-crisis period. The average funding basis is 58.70 basis points, but reached levels of 200 basis points or more during the LTCM hedge fund crisis of 1998, the Treasury buybacks of 2000–2002, and the financial crisis of 2008. We show that the size of the funding basis during the pre-crisis period can be accounted for by debt overhang costs. In contrast, the post-crisis funding basis is consistent with a scenario in which the costs of capital regulation become the dominant factor affecting balance sheet usage costs, with debt overhang costs remaining an important factor.

Second, we find that the funding basis is directly linked to the cost of balance sheet usage throughout the sample period. As an exogenous instrument for the cost of balance sheet usage, we use the impact on Libor rates of loans that remain on balance sheet over the year-end. This impact is readily identified from the turn-of-the-year effect on Libor rates as reflected in eurodollar (Libor) futures. To illustrate, Figure 1 plots the term structure of eurodollar futures prices (shown as deviations from a smoothed term structure) on January 3, 1994. As shown, the implied Libor rates for contracts with December expirations—which reference 3-month Libor rates for loans that extend over a year-end—are significantly higher than those for the other contracts. We show that changes in the funding basis are significantly related to changes in the size of the turn-of-the-year premium in Libor rates throughout the 1991–2018 sample period. These results parallel and extend those of Du, Tepper, and Verdelhan (2018), who demonstrate that CIP arbitrage during the post-crisis period is related to the proximity to the end of a quarter.

Third, the results allow us to test alternative theories about the nature of the costs of balance sheet usage faced by financial intermediaries. We begin by examining the implications of Duffie (2018), Andersen, Duffie, and Song (2019), and others who argue that debt overhang effects may impose significant costs on existing shareholders when intermediaries place additional financial assets on their balance sheets. To explore this, we study the relation between the funding basis and proxies for the debt overhang effect motivated by structural credit models, such as Merton (1974), Black and Cox (1976), and Longstaff and Schwartz (1995), as well as by reduced-form credit models. The results provide strong support for the debt overhang hypothesis. We find that the funding basis is significantly related to intermediary credit spreads, interest rates, equity market

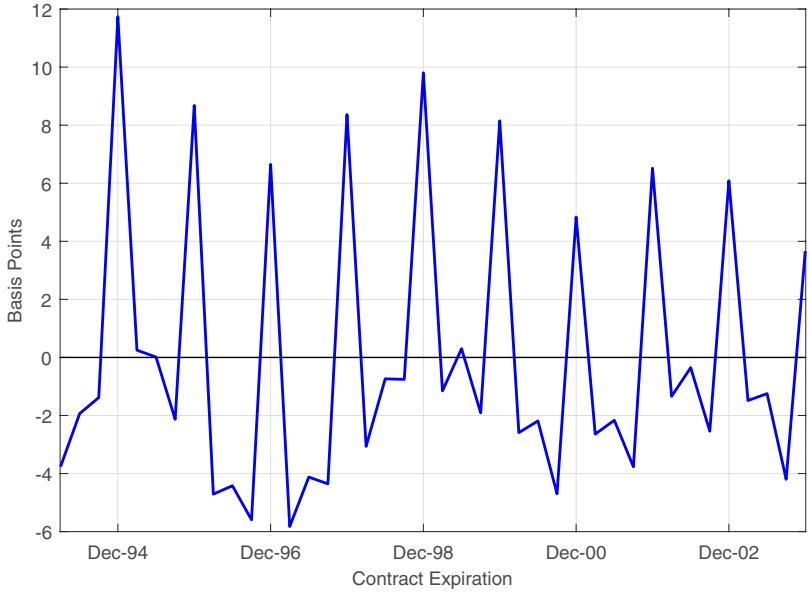

Figure 1
Turn-of-the-year effect in eurodollar futures prices
This figure shows the deviations of eurodollar futures prices from a cubic-spline-smoothed eurodollar futures curve as of January 3, 1994.

volatility, and bank stock returns in ways consistent with the debt overhang hypothesis. We also examine the implications of the capital regulation literature about the balance sheet costs faced by financial intermediaries. In particular, we find that the funding basis increases when intermediaries are required to hold more regulatory capital. This provides support for the hypothesis that capital regulation imposes significant balance sheet usage costs on intermediaries which, in turn, affect the balance sheet rental costs charged by institutions providing liquidity in the derivatives market.

Finally, we extend the analysis to the basis or mispricing between cash-derivatives pairs in some of the other largest derivatives markets. In particular, previous research documents a significant basis between securities and their derivative/synthetic counterparts in the interest rate swap, foreign exchange forward, agency mortgage-backed security, credit default swap, and TIPS markets. We find that changes in the cash-derivatives bases in all of these markets are significantly related to the turn-of-the-year instrument for the cost of renting intermediary balance sheet space.

These results have a number of important implications. First, they provide evidence that the cost of renting balance sheet space from financial intermediaries may help resolve a number of perplexing asset pricing puzzles. Second, these results shed light on the current debate among derivatives market

participants about proposals to migrate from Libor to other reference rates, such as the effective Fed funds rate (OIS) or the secured overnight funding rate (SOFR). Our findings suggest that the use of cash market risk-free rates may not be fully consistent with derivatives valuation in the financial markets. Third, since cash-derivatives funding bases can be viewed as instruments for the impact of capital constraints and regulatory requirements on financial institutions, they provide a direct way for monetary policy authorities, regulators, and other market participants to measure the impact of these constraints on financial markets and the economy . Our results suggest that these impacts can be large, that they vary significantly through time, and that they played an important role in markets long before the 2008 financial crisis.

1. Related Literature

The paper nearest to ours is Du, Tepper, and Verdelhan (2018). They uncover large and persistent violations of the CIP relation in a number of major currencies. By definition, these violations can be interpreted as wedges between the implied funding rate incorporated into currency forward contracts and the spot interest rates in the respective cash markets. Du, Tepper, and Verdelhan (2018) provide compelling evidence that these violations are linked to intermediary balance sheet factors in the post-crisis period. Our paper complements Du, Tepper, and Verdelhan (2018) by showing that their results can be extended to periods much earlier than the post-crisis period in other large derivatives markets.

This paper also contributes to the literature on the pricing of derivatives by uncovering a large funding-related basis between Treasury note futures and Treasury notes. Other studies documenting bases between securities and their derivative/synthetic counterparts include Longstaff, Mithal, and Neis (2005), Duffie (2010), and Bai and Collin-Dufresne (2019) (corporate bonds vs. CDS contracts); Du, Tepper, and Verdelhan (2018) (violations of CIP); Fama and French (1987, 1988) (commodities vs. futures contracts); Gabaix, Krishnamurthy, and Vigneron (2007), Duarte, Longstaff, and Yu (2007), Stanton and Wallace (2011), Chernov, Dunn, and Longstaff (2017), Boyarchenko, Fuster, and Lucca (2019), and Song and Zhu (2019) (mortgage-backed securities vs. mortgage derivatives); Liu, Longstaff, and Mandell (2006), Duarte, Longstaff, and Yu (2007), Jermann (2019), and Klingler and Sundaresan (2019) (interest rate swap spreads); Brenner, Subrahmanyam, and Uno (1989), and Constantinides, Jackwerth, and Savov (2013) (stock indexes vs. stock index futures and options); Fleckenstein, Longstaff, and Lustig (2014) and Haubrich, Pennacchi, and Ritchken (2012) (Treasury TIPS vs. inflation swaps); Longstaff and Rajan (2008), Coval, Jurek, and Stafford (2009), and Longstaff and Myers (2014) (corporate securities vs. synthetic CDOs); Ronn and Ronn (1989), Longstaff (1995), and

Van Binsbergen, Diamond, and Grotteria (2019) (options vs. stock indexes); and Pasquariello (2014, 2018), (American depository receipt parity).

We also contribute to the rapidly growing literature on the relation between asset pricing and intermediary costs and/or constraints. Examples include Chowdhry and Nanda (1998), Xiong (2001), Kyle and Xiong (2001), Gromb and Vayanos (2002), Krishnamurthy (2003, 2010), Brunnermeier and Pedersen (2009), Adrian and Shin (2010), Gârleanu and Pedersen (2011), He and Krishnamurthy (2012, 2013), Adrian, Etula, and Muir (2014), Kondor and Vayanos (2014), Pasquariello (2014, 2018), He, Kelly, and Manela (2017), Adrian, Boyarchenko, and Shachar (2017), and Chen, Joslin, and Ni (2019). An important emerging stream of this literature specifically focuses on the costs incurred by financial intermediaries from holding positions on their balance sheets. For example, Duffie (2018) and Andersen, Duffie, and Song (2019) emphasize the role that debt overhang costs may play in the investment decisions made by financial intermediaries. Another stream of the literature focuses on the costs imposed on financial intermediaries from post-crisis capital regulation, such as the Dodd-Frank Act, the Volcker Rule, and the SLR and LCR ratios of Basel III. Examples include Adrian et al. (2013, 2015, 2017), Kisin and Manela (2016), Bao, O'Hara, and Zhou (2018), Allahrakha, Cetina, and Munyan (2018), and Boyarchenko et al. (2018). This paper presents evidence that both debt overhang costs and the costs imposed by capital requirements are reflected in the cost of renting balance sheet space from financial intermediaries both pre- and post-crisis.

2. Derivatives and Balance Sheet Rental Costs

To illustrate the intuition of how balance sheet rental costs could affect the pricing of derivatives, we use a simple model of financial intermediation in the derivatives market in which intermediaries face balance sheet usage costs. This model incorporates a number of key elements from important recent papers modeling balance-sheet-constrained financial intermediaries, such as Andersen, Duffie, and Song (2019). Although we present the model in a futures context, the model could easily be adapted to any derivatives contract.

In this model, we focus on the pricing decisions of a constrained intermediary providing liquidity in the futures market. The intermediary is risk neutral and maximizes expected profits. Risk neutrality, however, does not play a significant role in the analysis, because we also assume that binding risk limits necessitate that the intermediary fully hedge all market-making activities. By holding risk fixed, this assumption has the important advantage of allowing us to differentiate between balance sheet usage costs and compensation for risk bearing.[5] The intermediary faces a fully competitive market populated with

[5] Alternatively, the intermediary simply could be assumed to be risk averse.

other intermediaries who face homogeneous balance sheet usage costs. This implies that the equilibrium expected profit of the intermediary is zero.

The financial intermediary is asked to provide binding price quotations for taking a position in a futures contract on a continuous basis. We assume that the potential customer wants to take a long position in the futures contract. Thus, the intermediary provides liquidity by taking a short position.[6] Paralleling Andersen, Duffie, and Song (2019), the price quotation is for a single atomistic contract. Thus, the pricing of the futures contract reflects the marginal balance sheet usage costs faced by the intermediary.

We focus on the case in which the intermediary is not leverage constrained (the constrained case is presented in Section A.1 of the Internet Appendix). In this scenario, the intermediary uses collateralized repo financing to the extent possible, and then uses unsecured borrowing to finance margins and haircuts, etc. To simplify notation, we assume that the intermediary provides quotations for a single-period Treasury note futures contract, and that all rates and costs are expressed relative to this single period. We denote the current or time-zero value of the underlying Treasury note as P, and denote its future random value at the contract expiration date as P_T. The Treasury note pays no coupon cash flows between time zero and futures expiration, because this time period is assumed to be short.[7] Let F denote the futures price at which the intermediary is willing to enter into a short position to provide liquidity to a potential customer. The implied funding rate for the futures contract—typically referred to as the implied repo rate—is denoted by r^* and defined by the expression

$$F = P\ (1+r^*). \tag{1}$$

Let r denote the repo rate for financing collateralized positions in Treasury notes. Furthermore, let r_U denote the marginal unsecured borrowing rate faced by the intermediary.

In taking a short position in the futures contract and hedging the risk via an offsetting long position in the underlying Treasury note, the financial intermediary faces constraints and frictions that impose costs on the use of its balance sheet. These constraints and frictions include—but are not limited to—margins, haircuts, regulatory capital restrictions and leverage constraints, and debt overhang costs. Like Kisin and Manela (2016), Andersen, Duffie, and Song (2019), and others, we do not impose a model of optimal capital structure to describe how these costs are funded, but simply specify a standard pecking order framework.[8] We express these costs in per unit terms as a percentage of the price P of the underlying Treasury note. Let m denote the percentage margin

[6] The analysis, however, is completely analogous when the customer wants to take a short position.

[7] This assumption is for expositional convenience only; incorporating intermediate coupons into the analysis is straightforward.

[8] In the framework of Andersen, Duffie, and Song (2019) and Song (2016), shareholders strictly prefer repo financing over unsecured debt financing, and, in turn, strictly prefer it over equity financing .

Table 1
Financial intermediary cash flows

Position	Time-zero cash flow	Expiration-date cash flow
Short futures contract	0	$F-P_T$
Long Treasury note	$-P$	P_T
Post/release futures margin	$-mP$	mP
Repo loan	$(1-h)P$	$-(1-h)(1+r)P$
Other costs	$-\theta P$	0
Unsecured borrowing	$(m+h+\theta)P$	$-(m+h+\theta)(1+r_U)P$
Total	0	$F-\left[1+(1-h)\,r+\theta+(m+h+\theta)\,r_U\right]\,P$

This table illustrates the cash flows associated with the financial intermediary taking a short position in a Treasury note futures contract and hedging it with a long position in the underlying Treasury note. P and P_T denote the current Treasury note price and the Treasury note price at the expiration of the futures contract, respectively. F denotes the futures price. r and r_U denote the repo rate and the unsecured borrowing rate, respectively. m and h denote the futures margin rate and the repo haircut rate, respectively. θ denotes the other balance sheet usage costs expressed as a fraction of the price of the Treasury bond.

the intermediary must post in taking a short futures position. Let h denote the percentage haircut the intermediary faces in financing its long position in the underlying Treasury note in the repo market. Note that because of the haircut, the intermediary can only borrow $(1-h)P$ via the repo market in financing the Treasury note. Finally, let θP denote the other per-period marginal balance sheet usage costs faced by the intermediary as part of the transaction (such as debt overhang costs or the costs of capital regulation).

The net profit to the intermediary is the total of all the cash flows associated with the transaction. To make the intuition more clear, Table 1 provides a summary of the various components of the transaction and their associated cash flows. In particular, the transaction involves first taking a short position in the futures contract. The value of the futures contract is zero at inception, so there is no initial cash flow associated with the contract. The intermediary, however, is required to post margin in the amount mP at time zero. At the expiration date, the futures contract is assumed to be cash settled, resulting in a cash flow of $F-P_T$, and the futures margin is then released back to the intermediary. To hedge the short position in the futures contract, the intermediary buys the underlying Treasury note at a price of P. At the expiration date, the Treasury note is sold at the market price of P_T. To finance the purchase of the Treasury note, the intermediary borrows $(1-h)P$ in the repo market. At expiration, the repayment of the repo loan results in a cash outflow of $-(1-h)(1+r)P$. We assume that the other balance sheet usage costs result in an immediate cash outflow of $-\theta P$. Finally, we assume that the residual cash flows at time zero are fully funded via unsecured borrowing, resulting in an additional cash inflow of $(m+h+\theta)P$. This fully-funded requirement implies that the net cash flow to the intermediary at time zero is zero. At the expiration date of the contract, the unsecured borrowing is repaid with interest, resulting in a cash outflow of $-(m+h+\theta)(1+r_U)P$.

Table 1 shows that since there is no initial net cash flow, the net profit to the intermediary from the transaction is simply the sum of the cash flows received

at the expiration date . Thus, the net profit is

$$F-[1+(1-h)\,r+\theta+(m+h+\theta)\,r_U]\;P. \tag{2}$$

The position is fully hedged, so the net profit is not random. Thus, maximizing expected net profit is equivalent to maximizing net profit from the perspective of the intermediary. In this competitive market, the intermediary earns zero profit in equilibrium. Imposing this equilibrium condition implies that the futures price quoted by the intermediary must satisfy

$$F=[1+(1-h)\,r+\theta+(m+h+\theta)\,r_U]\;P. \tag{3}$$

Finally, substituting in from Equation (1) and solving for the implied repo rate r^* gives

$$r^*=r+h\;(r_U-r)+\theta\;(1+r_U)+m\;r_U. \tag{4}$$

This equation illustrates how the implied funding rate r^* in the futures market can differ from the financing rate r in the underlying cash market.

This simple model also illustrates the sense in which a potential customer rents balance sheet space from the financial intermediary when taking a synthetic position in the security via derivatives.[9] Taking the other side of the transaction requires the intermediary to place the security on its balance sheet as a hedge and incur both repo costs and a number of indirect balance sheet usage costs. Thus, the funding basis r^*-r can be interpreted as the cost of renting balance sheet space from the intermediary.

3. The Data

In this study, we focus first on the balance sheet rental costs associated with taking synthetic positions in Treasury securities. A key advantage of this is that there are liquid futures markets for Treasury notes and bonds as well as an active repo market for financing Treasuries. Thus, we can solve for the implied funding rates in the futures market and directly observe the financing rates for Treasuries in the repo market. As discussed earlier, interest rate futures are among the very largest of all derivative markets.[10]

As a specific example, we focus on 5-year Treasury notes and Treasury note futures, because they are among the most-actively-traded Treasury securities and futures contracts during the sample period. Brandt, Kavajecz, and Underwood (2007) and Mizrach and Neely (2008) find that price discovery in the Treasury futures market is most efficient for the 5-year Treasury note

[9] A synthetic position allows the customer to achieve the same exposure to the underlying asset without having to pay the full value of the asset up-front. Thus, derivative contracts provide synthetic leverage for positions. See the discussion in Tuckman (2013) and Eisfeldt and Rampini (2009).

[10] The Internet Appendix provides a detailed overview of the Treasury note futures markets (Section A.3) and Treasury repo markets (Section A.4), along with descriptions and source information for all the data and variables used in the paper (Table A2).

Table 2
Summary statistics for 5-year Treasury note futures contracts

Year	Months	Vol	Open	Min	Ave	Max	Num	Time	Coup	Init	Maint
1991	9, 12	8,573	40,902	98.61	101.69	106.83	9.00	5.0146	7.5139	945	700
1992	3, 6, 9, 12	11,349	51,118	99.91	105.29	111.61	12.00	5.0021	6.2552	945	700
1993	3, 6, 9, 12	14,316	64,818	102.25	109.20	114.23	10.75	5.0015	5.3819	945	700
1994	3, 6, 9, 12	22,791	76,257	100.34	106.51	113.03	9.00	5.0018	5.9653	945	700
1995	3, 6, 9, 12	23,967	68,741	99.06	104.41	109.89	9.25	5.0032	6.7292	945	700
1996	3, 6, 9, 12	19,385	59,949	103.72	107.08	111.41	9.50	5.0010	6.0855	1,215	900
1997	3, 6, 9, 12	34,984	85,659	103.53	106.29	108.73	10.00	5.0012	6.2171	1,114	825
1998	3, 6, 9, 12	37,994	128,712	106.09	110.01	115.97	8.50	5.0007	5.6083	996	738
1999	3, 6, 9, 12	33,240	121,282	106.84	110.77	116.28	3.25	5.0012	5.2500	1,148	850
2000	3, 6, 9, 12	46,733	192,308	96.41	99.11	103.16	2.50	5.0027	5.9250	890	638
2001	3, 6, 9, 12	60,960	193,859	99.69	103.65	110.31	2.00	5.0027	5.1563	1,080	800
2002	3, 6, 9, 12	99,494	277,615	99.95	104.10	114.34	2.50	5.0027	3.7500	1,316	975
2003	3, 6, 9, 12	139,884	381,226	99.95	105.82	117.69	5.00	5.0030	3.2500	1,215	900
2004	3, 6, 9, 12	180,505	506,283	100.00	106.70	115.19	10.50	5.0029	3.3125	979	725
2005	3, 6, 9, 12	201,067	503,477	105.13	107.87	112.47	11.00	5.0015	3.8188	675	500
2006	3, 6, 9, 12	228,294	468,111	102.88	105.98	109.20	10.50	5.0014	4.4313	540	413
2007	3, 6, 9, 12	307,668	739,017	102.88	105.54	111.06	11.25	5.0030	4.4813	827	613
2008	3, 6, 9, 12	349,527	844,175	103.17	109.75	122.30	11.00	5.0029	3.3750	1,586	1,175
2009	3, 6, 9, 12	201,325	422,587	107.97	114.43	120.48	10.75	5.0010	2.4605	1,384	1,025
2010	3, 6, 9, 12	259,126	424,303	110.10	116.39	122.25	11.00	5.0015	2.1000	1,131	838
2011	3, 6, 9, 12	353,301	647,732	109.32	117.47	124.13	10.75	5.0032	1.5789	1,215	900
2012	3, 6, 9, 12	275,396	656,619	112.60	120.77	124.95	10.25	5.0027	0.9188	810	600
2013	3, 6, 9, 12	348,569	808,238	118.46	122.14	124.77	10.50	5.2021	0.9438	866	756
2014	3, 6, 9, 12	392,439	1,002,394	117.70	120.41	124.42	11.00	5.2019	1.4813	990	900
2015	3, 6, 9, 12	391,657	1,011,450	117.00	119.06	121.35	11.00	5.0026	1.5188	990	900
2016	3, 6, 9, 12	400,171	1,331,065	117.21	119.78	122.51	10.75	5.0030	1.3816	949	863
2017	3, 6, 9, 12	447,404	1,421,403	116.01	118.48	122.48	10.25	5.0017	1.6250	770	700
2018	3, 6, 9, 12	563,798	1,690,414	111.91	114.71	118.60	10.50	5.2021	2.3688	732	665
Average		198,976	528,347	96.41	110.87	124.95	9.03	5.0428	3.6596	998.41	773.58

This table presents summary statistics for the 5-year Treasury note futures contracts. Year and months refer to the year and contract expiration months during that year in the sample. Vol and open refer to the average daily total trading volume and open interest across all Treasury note future contracts traded during the year. Min, Ave, and Max refer to the minimum, average, and maximum prices for the futures contracts during the year. Num, Time, and Coup refer to the average number of notes deliverable, the average time to maturity at issuance of the deliverable notes, and the average coupon rates for the deliverable bonds for all contracts during the year. Init and Maint refer to the average initial and maintenance margins for speculators for the year (expressed as dollars per contract).

futures contract. Furthermore, the design of the Chicago Mercantile Exchange's (CME) 5-year Treasury note futures contract has the important advantage of minimizing the value of the timing and cheapest-to-deliver options implicit in Treasury futures contracts.[11]

We collect data for 5-year Treasury note futures prices, trading volume, open interest, and margins from Bloomberg. Overall, we have data for the 110 futures contracts with quarterly expirations during the June 1991 to December 2018 sample period. For each futures contract, we also identify the set of deliverable Treasury notes and collect information about their coupon rates, maturity dates, conversion factors, and prices from Bloomberg. Table 2 presents summary statistics for the Treasury note futures contracts.

[11] Our methodology explicitly considers the cheapest-to-deliver option in futures prices, but abstracts from several minor options, such as the timing option. We note, however, that abstracting from these other options may slightly understate the size of the funding basis.

We also collect repo data for 5-year Treasury note collateral from GovPX via Datastream. Specifically, we collect the daily index of overnight volume-weighted repo rates for on-the-run 5-year Treasury notes transacted by brokers and dealers in the bilateral repo market as of 6 p.m. EST. An important advantage of using repo rates specific to 5-year Treasury notes rather than general collateral repo rates is that they more accurately reflect the actual financing costs of an intermediary providing liquidity in 5-year Treasury note futures contracts. The reason is that 5-year Treasury notes often can be financed at special repo rates that are substantially below general collateral repo rates during periods when the supply of 5-year Treasury collateral is tight relative to the demand for these specific maturities. In particular, the specialness of 5-year Treasury notes became a major factor affecting their financing costs during flights-to-safety in the 1990s as well as the extensive U.S. Treasury buyback program of the early 2000s.[12]

We supplement the special collateral repo rates with data on general collateral bilateral Treasury repo rates for overnight; 1-, 2-, and 3-week; and 1-, 2-, 3-, 4-, 5-, and 6-month horizons from the Bloomberg system. These repo rates are provided by a large interdealer broker (ICAP/Tullett Prebon).[13]

4. The Funding Basis

The funding basis in Treasury note futures is estimated using a two-step procedure. In the first step, we solve for the funding rate implicit in the 5-year Treasury note futures contract, which is known as the implied repo rate. In the second step, we subtract the actual repo rate for financing 5-year Treasury notes from the implied repo rate.[14]

To illustrate how the implied repo rate is computed, consider the simple case where the currently cheapest-to-deliver note eligible for delivery into the futures contract does not pay any coupons between now and the expiration date of the contract.[15] In this situation, the implied repo rate r^* defined in Equation (1) is given by (where we now take into account the maturity of the contract)

$$r^* = \frac{F - P}{P} \times \frac{360}{N}, \tag{5}$$

[12] For a discussion of special repo rates, see Duffie (1996).

[13] We use bilateral Treasury repo rates, which are continuously available throughout the entire sample period, and term repo rates, which are available for horizons ranging from overnight to 6 months. This latter feature is particularly important in allowing us to match the maturity of the repo rate with that of the futures contracts. In contrast, tri-party and GCF repo rate data are publicly available only for the last part of the sample period and typically only for overnight repo transactions. Section A.4 of the Internet Appendix describes the differences between the bilateral, tri-party, and GCF repo markets in detail and provides a full description of the methodology used in constructing the repo data set.

[14] Section A.5 of the Internet Appendix provides the full details on the methodology used.

[15] The cheapest-to-deliver note is the note with highest implied repo rate among all notes eligible for delivery into the Treasury note futures contract. See Burghardt and Belton (2005) and Choudhry (2006).

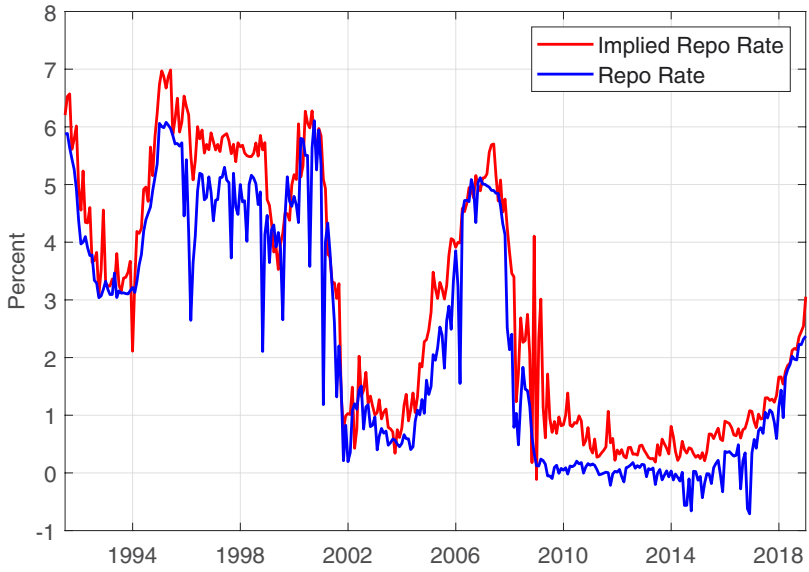

Figure 2
Implied repo and repo rates
This figure shows the implied repo rate from 5-year Treasury note futures contracts and the corresponding term 5-year Treasury note repo rate. Monthly averages of daily rates are shown.

where F is the futures price for the cheapest-to-deliver note, P denotes the current market price of that note, and N denotes the number of days until the expiration date of the contract. The futures price F is obtained by making a small adjustment to the market futures price to back out the value of the cheapest-to-deliver option the contract confers on the seller. In general, the value of the option is relatively small due to the high correlation among the notes that are eligible for delivery into the 5-year Treasury note futures contract.[16]

Figure 2 plots the time series of implied repo rates and repo rates during the sample period. As shown, both implied repo rates and repo rates vary significantly over time, with both taking their highest values during the 1990s, and their lowest values during the 2008–2018 post-crisis period. Despite the wide range of variation, however, Figure 2 shows that the implied repo rate is generally higher than the repo rate throughout most of the sample period. This implies that balance sheet costs exist throughout the sample and not just as a result of post-crisis capital regulation.

Table 3 presents summary statistics for the estimated funding basis. The funding basis is predominantly positive throughout the sample period and is significant from both a statistical and economic perspective. In particular, the

[16] The median value of the cheapest-to-deliver option is only 0.0630 per $100 par amount. Furthermore, the post-crisis median value is only 0.0452 per $100 par amount.

Table 3
Summary statistics for the funding basis

Year	Mean	Positive	SD	5%	50%	95%	*N*
1991	60.97	95.95	45.65	2.35	54.45	162.39	148
1992	47.66	78.26	63.72	−26.91	32.82	177.88	253
1993	11.61	65.61	64.89	−138.49	13.70	107.09	253
1994	59.70	93.28	59.79	−2.27	51.26	160.20	253
1995	75.95	92.80	73.44	−9.41	68.16	186.03	250
1996	122.00	96.83	107.97	9.98	84.62	342.02	252
1997	83.14	93.20	75.78	−10.96	68.00	203.84	250
1998	103.00	92.40	127.97	−13.90	68.40	387.35	250
1999	10.85	42.00	103.12	−98.73	−15.06	232.96	250
2000	49.21	58.73	120.31	−81.67	21.99	295.74	252
2001	76.40	68.25	141.43	−87.39	58.95	427.06	252
2002	22.06	58.80	72.72	−82.81	14.27	138.52	250
2003	27.33	69.84	61.54	−62.08	25.41	121.39	252
2004	67.17	94.42	51.82	−2.43	56.53	163.53	251
2005	94.17	88.40	86.81	−17.10	73.18	263.40	250
2006	27.98	46.80	109.77	−41.19	−3.51	366.71	250
2007	61.38	78.09	88.73	−37.10	49.71	256.43	251
2008	105.41	84.58	152.41	−98.50	77.28	392.62	253
2009	112.69	98.81	87.25	32.12	85.51	304.56	252
2010	70.26	98.02	41.42	8.88	70.19	142.16	253
2011	45.09	92.09	44.91	−6.59	40.60	128.83	253
2012	29.46	93.28	23.14	−2.80	26.56	69.69	253
2013	40.88	94.44	36.98	−1.75	38.51	96.60	252
2014	57.55	92.46	56.67	−2.64	45.57	144.35	252
2015	58.26	96.84	42.95	3.27	53.66	141.67	253
2016	69.22	94.84	76.68	−0.98	47.35	262.32	252
2017	32.92	86.45	47.54	−13.14	25.70	122.62	251
2018	22.29	78.57	43.46	−20.88	16.11	98.45	252
All	58.70	82.83	87.90	−43.42	43.68	218.36	6,943

This table presents summary statistics for the funding basis, which is computed as the difference between the implied repo rate and the corresponding term repo rate and is expressed in basis points. Positive refers to the percentage of observations that are positive. The columns with headings 5%, 50%, and 95% indicate the 5th, 50th, and 95th percentiles of the distribution. *N* means the number of observations. The sample period is from June 3, 1991 to December 31, 2018.

average value of the funding basis during the entire sample period is 58.70 basis points and is highly statistically significant. Furthermore, the average value of the funding basis is positive for all 28 years in the sample period. Overall, 82.83% of the funding basis estimates are positive. Furthermore, the percentage of positive estimates is greater than 90% for 15 of the 28 years in the sample period.

Figure 3 plots the time series of the funding basis throughout the sample period. The plot confirms that the funding basis is predominantly positive. As shown, however, it varies significantly over time. The funding basis typically lies in the range of zero to 100 basis points, but there are clearly periods during which its value is higher or lower. Figure 3 also shows that a number of the extreme values appear to coincide with major disruptive events in the financial markets. For example, the funding basis spikes during the Asian financial crisis, the long-term capital management (LTCM) crisis, and the 2008 financial crisis. This pattern is consistent with the implications of He and Krishnamurthy (2013) about the effects of shocks to intermediary frictions on their funding

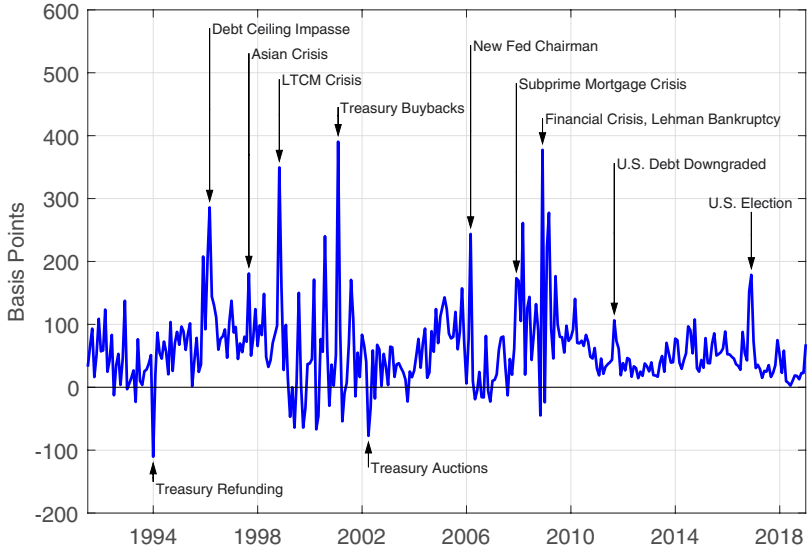

Figure 3
Funding basis
This figure plots the time series of the funding basis. The funding basis is computed as the difference between the implied repo rate and the corresponding term 5-year Treasury note repo rate.

costs. Furthermore, many of the extreme values occur during the U.S. Treasury buyback program of 2000–2002.

5. Properties of the Funding Basis

Before turning our attention to studying the underlying sources of the funding basis, we first provide some broad perspective on its magnitude and properties.

5.1 The size of the funding basis

The average value of the funding basis is 58.70 basis points over the entire 1991–2018 sample period, 58.79 basis points during the 1991–2007 pre-crisis period, and 58.56 basis points during the 2008–2018 post-crisis period. At first glance, these averages may appear larger than the values we might expect, particularly during the pre-crisis period when balance sheet usage costs were likely to consist primarily of debt overhang costs. Andersen, Duffie, and Song (2019) show that debt overhang costs should be approximately equal to intermediary credit spreads. Thus, the average value of the funding basis during the pre-crisis period appears roughly 20 basis points larger than standard measures of intermediary credit spreads, such as the Libor-Treasury spread, which averaged 41.31 basis points during the 1991–2007 period, or the CDS spread for an index of broker-dealers which averaged 30.06 basis points during the 2001–2007 period. This raises the natural question of why the funding basis appears

somewhat larger than standard measures of intermediary credit spreads during the pre-crisis period before we would expect capital regulation to play a major role.[17]

The answer is that conventional measures of intermediary credit spreads, such as the Libor-Treasury spread or CDS spreads, often represent an underestimate of the actual effective credit spread $r_U - r$ faced by institutions providing intermediation in the Treasury note futures market. The reason for this is that intermediaries were often able to finance specific collateral, such as 5-year Treasury notes, at special repo rates that were substantially lower than other riskless rates during flights-to-safety or other times when 5-year Treasury notes were in tight supply. During flights-to-safety or at times when the supply of specific Treasury collateral is tight, repo lenders are often willing to provide repo financing to intermediaries at very low rates in order to be able to obtain access to specific Treasury securities as collateral for the repo loan (see Duffie 1996). During these periods, the spread between the unsecured financing rate r_U and the secured repo financing rate r for 5-year Treasury notes can increase dramatically and be much wider than the conventional measures of intermediary credit spreads mentioned above.

To explore this, we more closely examine the role that repo financing rates for 5-year Treasury collateral plays during periods in which the funding basis displays large spikes. To illustrate this, Figure 4 plots both the implied repo rate and the repo rate for several periods during the earlier pre-crisis portion of the sample in which large values of the funding basis occur. In particular, Figure 4 plots the implied repo and repo rates during the Asian financial crisis of 1997, the LTCM crisis of 1998, and the Treasury buyback program of 2000–2002. As shown, an important common thread runs throughout each of these examples. In each instance, while the implied repo rate r^* remains relatively stable, there is a precipitous decline in the repo rate r for 5-year Treasury notes which then results in a large upward spike in the funding basis $r^* - r$.

The Asian financial crisis began in late June/early July 1997 with large declines in the exchange rates of a number of Asian countries. On July 2, 1997, Thailand devalued its currency, lowering its value by as much as 20%, and requested IMF assistance. On July 11, 1997, the Philippine Peso was devalued. On July 18, 1997, the IMF announced emergency measures to take pressure of the Philippine Peso. On August 5, 1997, Thailand agreed to strict IMF economic terms to obtain a $17 billion loan. As shown, the repo rate for 5-year Treasury notes declined by more than 400 basis points during the first 2 weeks of August, resulting in a spike in the funding basis which reached nearly 500 basis points by mid-August.[18]

[17] We are grateful to the referee for raising this important issue.

[18] See Radelet et al. (1998) for a discussion of the Asian financial crisis.

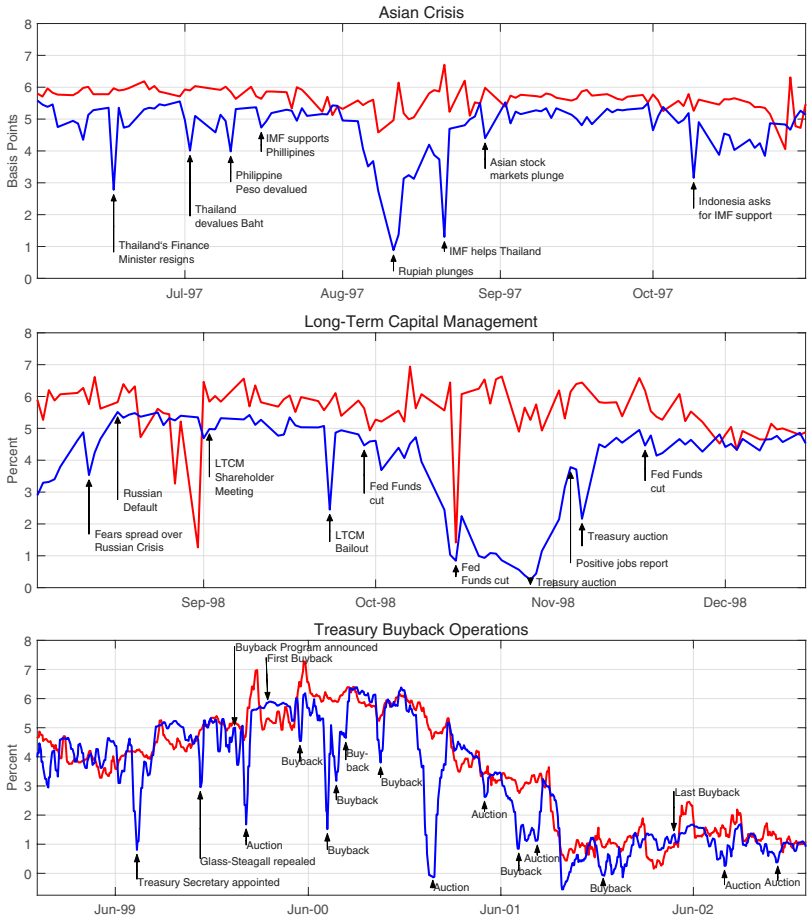

Figure 4
Implied repo and repo rates during specific events
This figure plots the time series of the implied repo and repo rates for the indicated event periods. The implied repo rate is in red, and the repo rate is in blue.

The LTCM crisis was precipitated by the August 17, 1998 announcement that the Russian government was devaluing the Ruble, defaulting on its domestic debt, and declaring a moratorium on the repayment of its foreign debt.[19] The ensuing flight-to-safety led to a dramatic increase in credit spreads in many fixed income markets. As a result, LTCM suffered heavy mark-to-market losses in its portfolio and ultimately collapsed on September 23, 1998. Shortly thereafter, the repo rate for 5-year Treasury notes declined by more than 300 basis points, causing the funding basis to reach levels in excess of 500 basis points. It is also

[19] See Duffie, Pedersen, and Singleton (2003) for a discussion of the Russian default crisis.

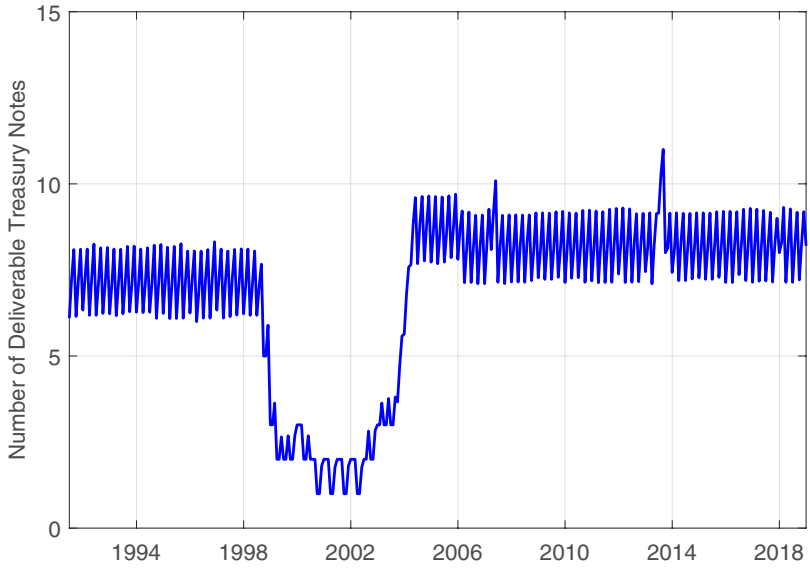

Figure 5
Number of Treasury notes eligible for delivery into the 5-Year Treasury note futures contract
This figure plots the number of Treasury notes that are eligible to be delivered into the 5-year Treasury note futures contract.

interesting to note that the implied repo rate decreases sharply on several key information dates during the LTCM crisis timeline. These episodes, however, are brief and are quickly reversed.

The Treasury buyback program of 2000–2002 is particularly relevant to understanding the dynamics of the funding basis, because many of the large positive and negative spikes occur during this period. As discussed by Han, Longstaff, and Merrill (2007), the announcement of the Treasury buyback program in January 2000 was followed by 45 buyback auctions from March 2000 to April 2002 in which the Treasury retired a total of $67.5 billion of its debt. In addition to retiring a large amount of its debt, the Treasury also began skipping auctions of 5-year notes, or simply reopening existing 5-year notes. The result of these activities was a large decline in the number and amount of 5-year Treasury debt issues, leading to frequent episodes in which tight supply caused 5-year Treasury notes to finance at a significantly lower special rate in the repo market. To illustrate the supply effects, Figure 5 plots the number of Treasury note issues deliverable into the 5-year Treasury note futures contract throughout the sample period. As shown, the number of deliverable issues is typically between six and ten during most of the study period, but declines dramatically during the 1999–2002 period when often only one or two issues are available to be delivered.

As we will show in the next section, the spread between unsecured intermediary financing rates and the secured repo rates for specific 5-year Treasury collateral almost completely accounts for the funding basis during the pre-crisis period.

5.2 The components of the funding basis

To provide some additional perspective on the relative size of funding basis, we take the simple approach of calibrating the balance sheet cost model in Equation (4) and comparing the observed value of the funding basis with values implied by the model. Specifically, the balance sheet costs in Equation (4) can be divided into four separate components: a haircut component $h(r_U - r)$, a margin component mr_U, a debt overhang component, and a residual capital regulation component (which could also include any other types of balance sheet costs). The sum of the two latter components constitute the $\theta(1+r_U)$ term in Equation (4).

To calibrate the margin m, we use the CME initial margin requirement for the individual futures contracts (see Table 2). Consistent with historical values for the repo haircut for 5-year Treasury notes, we use a constant value of 2% for h.[20] To capture the debt overhang component, we use the model of debt overhang costs presented in Proposition 1 of Andersen, Duffie, and Song (2019). Section A.6 of the Internet Appendix shows that their model implies that the debt overhang component can be represented as $e^{-r_U T}(r_U - r)$ where T is the time until contract expiration. As the measure of the unsecured intermediary financing rate r_U, we use the 1-month financial commercial paper rate.[21] As before, the secured financing rate r is the repo rate for 5-year Treasury collateral.

Once the haircut, margin, and debt overhang components are calibrated, we can solve for the implied value of the capital regulation component by subtracting the calibrated values of the first three components from the funding basis. We can then directly examine whether the magnitude of the implied capital regulation component appears to be plausible.[22]

Table 4 presents summary statistics for the individual components of the funding basis. As shown, the results for the implied capital regulation component appear both plausible and intuitive. In particular, the average value of the implied capital regulation component during the pre-crisis period is slightly negative but is not significantly different from zero. In contrast, the average value of the implied capital regulation component during the post-crisis period is 31.94 basis points which would appear to be a realistic figure.

[20] Stigum (1990), table 13-1) implies repo haircuts of roughly 2% during the 1990s. Krishnamurthy, Nagel, and Orlov (2014) provide evidence that repo haircuts were close to 2% during the 2006–2010 period. The Federal Reserve Bank of New York reports that the median repo haircut in the tri-party/GCF repo markets for U.S. Treasuries during the 2010–2018 period was 2%.

[21] The results are robust to alternative measures of the unsecured financing rate, such as the 1-, 2-, and 3-month Libor rates.

[22] We are grateful to Stijn Van Nieuwerburgh for suggesting this approach.

Table 4
Summary statistics for the components of the funding basis

	Pre-crisis	Post-crisis	Full sample
Component	1991–2007	2008–2018	1991–2018
Haircut component	1.17	0.51	0.91
Margin component	4.00	0.68	2.67
Debt overhang component	58.76	25.43	45.43
Implied capital regulation component	−5.15	31.94	9.69
Total funding basis	58.79	58.56	58.70
N	4,167	2,776	6,943

This table reports the average values of the individual components of the funding basis based on the calibrated balance sheet cost model. All of the components are measured in basis points. The sample period is daily from June 1991 to December 2018.

These results are consistent with a scenario in which the balance sheet impact of capital regulation was relatively modest prior to the financial crisis, but became a much more significant factor during the post-crisis period.

The results in Table 4 also imply that the size of the funding basis is very consistent with the calibrated values of the various components of the balance sheet cost model. In particular, the average value of the funding basis during the pre-crisis period closely matches that of the debt overhang component. Thus, debt overhang costs have the potential to almost fully account for the funding basis during this period. In contrast, the margin, haircut, and debt overhang components by themselves only account for about half of the funding basis during the post-crisis period. As discussed above, however, the residual part of the funding basis may be explainable in terms of the incremental costs imposed on intermediaries by post-crisis capital regulation. In summary, the estimated funding costs do not appear too large in relation to realistic measures of balance sheet usage costs.

Figure 6 plots the time series of the individual components during the sample period. As shown, the haircut and margin components are relatively small. In contrast, the debt overhang component is very significant throughout the entire sample period, but takes its largest values during the pre-crisis period, particularly during the 2000–2002 Treasury buyback program. Finally, the implied capital regulation component is generally positive during the earlier and later portions of the pre-crisis period, but becomes negative during the Treasury buyback period. The implied capital regulation component becomes significantly larger and almost uniformly positive during the post-crisis period.

5.3 Comparison to other bases

Finally, comparing the magnitude of the funding basis to that of other similar types of bases previously documented in the literature is also useful.

Recall from Table 4 that the average size of the funding basis is 58.70 basis points for the 1991–2018 period, 58.79 basis points for the 1991–2007 pre-crisis period, and 58.56 basis points for the 2008–2018 post-crisis period.

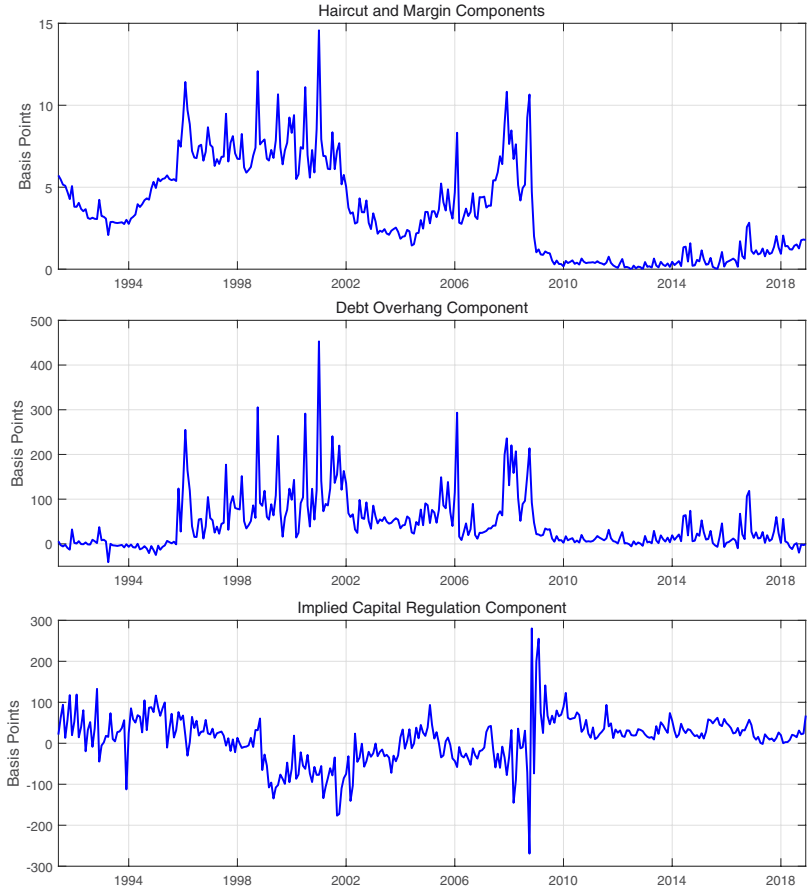

Figure 6
Components of the funding basis
This figure plots the time series of individual components of the funding basis based on the calibrated balance sheet cost model.

Du, Tepper, and Verdelhan (2018) provide evidence of significant and persistent violations of CIP in the foreign exchange market. Their results imply that the average 3-month CIP basis is 13.93 basis points for the 2000–2016 period, 2.99 basis points for the 2000–2007 pre-crisis period, and 23.66 basis points for the 2008–2016 post-crisis period.

Song and Zhu (2019) show a significant basis in the dollar roll market. Their results indicate that the average dollar roll specialness for the closest-to-par mortgage-backed securities is 39.67 basis points for the 1998–2013 period, 30.42 basis points for the 1998–2007 pre-crisis period, and 55.42 basis points for the 2008–2013 post-crisis period.

Fleckenstein, Longstaff, and Lustig (2014) document a large basis between the prices of Treasury TIPS that have been swapped into synthetic nominal bonds and actual nominal Treasury bonds. Their results indicate that the average basis is 39.56 basis points for the 2004–2011 period, 27.62 basis points for the 2004-2007 pre-crisis period, and 50.71 basis points for the 2008–2011 post-crisis period.

These examples illustrate that, although the funding basis was somewhat larger than other similar bases during the pre-crisis period, its overall size is roughly on the same order of magnitude as the other bases, particularly during the post-crisis period. These results raise the possibility that many of the bases that have been documented in the literature may be driven by common factors. We will explore this possibility later in the paper.

6. The Link to Balance Sheet Usage

What are the fundamental causes of the large basis between implied funding rates in derivatives contracts and financing rates in the cash market? Motivated by the literature on intermediary asset pricing, we begin by examining the relation between the funding basis in the Treasury note futures market and the cost of balance sheet usage by financial intermediaries.

6.1 Quarter-end effects

In their analysis of violations of the CIP relation, Du, Tepper, and Verdelhan (2018) provide compelling "smoking gun" evidence of the link between the mispricing of foreign exchange forwards and intermediary balance sheet usage. Specifically, they show that the magnitude of the mispricing in the post-crisis period is directly related to the proximity to the end of a quarter.

Following Du, Tepper, and Verdelhan (2018), we also test for a quarter-end effect in the funding basis. In doing this, we regress the daily estimates of the funding basis on quarterly dummy variables that take value one when the horizon of a futures contract straddles the end of a quarter, and zero otherwise. Given the quarterly cycle of the expiration dates of the Treasury note futures contracts, it is important to include time-to-expiration controls in the regression in order to identify the quarter-end effect separately. We also include controls for the time-series properties of the funding basis. Finally, we include day-of-the-week fixed effects and fixed effects for individual years. Table 5 reports the results from these regressions.

Table 5 complements Du, Tepper, and Verdelhan (2018) by showing that their results extend to the interest rate futures market. In particular, the results show that the funding basis in Treasury note futures contracts is about 8.3 basis points higher for contracts that straddle the end of a quarter than for contracts that do not. Furthermore, the funding basis for contracts that straddle the end of the year is about 10.8 basis points higher. These values are statistically significant and are on the same order of magnitude as those observed by

Table 5
Regression tests for quarter-end effects

Variable	Coefficient	t-stat	Coefficient	t-stat
March	6.01144	1.51	–	–
June	7.94013	1.99**	–	–
September	7.84250	1.97**	–	–
December	10.78558	2.48***	–	–
Quarter-end	–	–	8.30070	2.34***
Time-series controls		Yes		Yes
Time-to-expiration controls		Yes		Yes
Fixed effects for day of week		Yes		Yes
Fixed effects for year		Yes		Yes
Adj. R^2		.507		.507
N		6,943		6,943

This table reports the results from regressions of the funding basis on its lagged values, control variables, and quarter-end dummy variables. The funding basis is measured in basis points. The time-series controls are the first five lagged values of the funding basis. The time-to-expiration controls are the number and squared number of days until the expiration date of the futures contract. March, June, September, and December are dummy variables that take a value of one for the respective months, and zero otherwise. Quarter-end is a dummy variable that equals one for the months of March, June, September, and December, and zero otherwise. The regression is estimated with fixed effects for the day of the week and fixed effects for individual years. The t-statistics are based on the Newey-West (1987) heteroscedasticity and autocorrelation consistent estimate of the covariance matrix. The sample period is daily from June 1991 to December 2018. $*p < .1$; $**p < .05$; $***p < .01$.

Du, Tepper, and Verdelhan (2018). These results provide strong evidence of a link between the funding basis and the costs faced by financial intermediaries in using their balance sheets.

6.2 Is the funding basis driven by balance sheet usage costs?

The results in Du, Tepper, and Verdelhan (2018) and Table 5 establish that funding bases are linked to intermediary balance sheet usage at the end of a quarter. To examine the effects of balance sheet usage costs on derivative prices at a deeper level, however, it is useful to have a quantitative measure of how these costs vary the rest of the time. As a measure of balance sheet usage costs, Du, Tepper, and Verdelhan (2018) use the spread between the interest on excess reserves rate (IOER) and Libor. This measure, however, is only available for the post-crisis period.

As a proxy for the cost of balance sheet usage, we use the turn-of-the-year premium in eurodollar futures prices. Eurodollar futures are contracts that settle based on the value of the 3-month Libor rate at their expiration date. This means that contracts with December expirations are based on the rate for Libor loans that remain on the balance sheet at year-end, while the contracts with March, June, and September expirations are not. Musto (1997), Griffiths and Winters (2005), and others show that financing rates, such as 3-month Libor, tend to spike near the end of a year as financial institutions face additional balance-sheet-related pressure to hold cash. Thus, the expected size in the spike in year-end Libor provides a measure of the balance sheet usage costs financial institutions face.

We calculate the turn-of-the-year premium as the difference between the futures price for a December contract and the average of the futures prices for the contracts expiring 3 months earlier/later (September/March).[23] Recall that the eurodollar futures price is the expected value of Libor at the contract expiration date (under the risk-neutral measure; see Cox, Ingersoll, and Ross 1981). Thus, the turn-of-the-year premium provides a continuous market-based measure of the difference between the expected value of Libor in December and the average expected value of Libor in the months bracketing December. As was illustrated in Figure 1, the expected value of Libor in December can be significantly higher than in months in which 3-month Libor does not span the end of a year.

Intuitively, the turn-of-the-year premium represents the incremental cost of balance sheet usage at year-end relative to other months (rather than the level of these costs). Changes in these incremental costs, however, should be reflective of variation in the tightness of the balance sheet constraints facing financial intermediaries. Thus, changes in the turn-of-the-year premium can be viewed as providing a simple "difference-in-differences" instrument for the time variation in the cost of balance sheet usage. We create an index of the turn-of-the-year premium by averaging its values over all futures contracts with December expirations. An important advantage of this measure of the cost of balance sheet usage is that it is continuously available throughout the entire 1991–2018 study period. Figure 7 plots the time series of the index.

Having an exogenous instrument for the cost of balance sheet usage by financial intermediaries now allows us to test whether the funding basis varies in response to changes in these costs. In doing this, our approach is to regress the funding basis on changes in the index of the turn-of-the-year premium. In these regressions, we include the lagged value of the funding basis as a control for its time-series properties. We also include month-of-the-year fixed effects and fixed effects for individual years. Table 6 reports the regression results.

The results provide direct evidence that the funding basis is driven by changes in balance sheet usage costs. Specifically, Table 6 shows a significant positive relation between the funding basis and changes in the turn-of-the-year premium. Furthermore, the positive relation is significant in the regression with fixed effects for individual years as well as in the regression without fixed effects for individual years.

6.3 The funding basis and dealer balance sheet usage

As a third way of exploring the relation between balance sheet usage costs and the funding basis, we examine whether changes in the funding basis forecast changes in balance sheet usage by financial intermediaries. In doing this, of course, we are not necessarily suggesting a causal relation between the funding

[23] Section A.6 of the Internet Appendix provides a detailed discussion of how the turn-of-the-year premium is calculated using eurodollar futures prices.

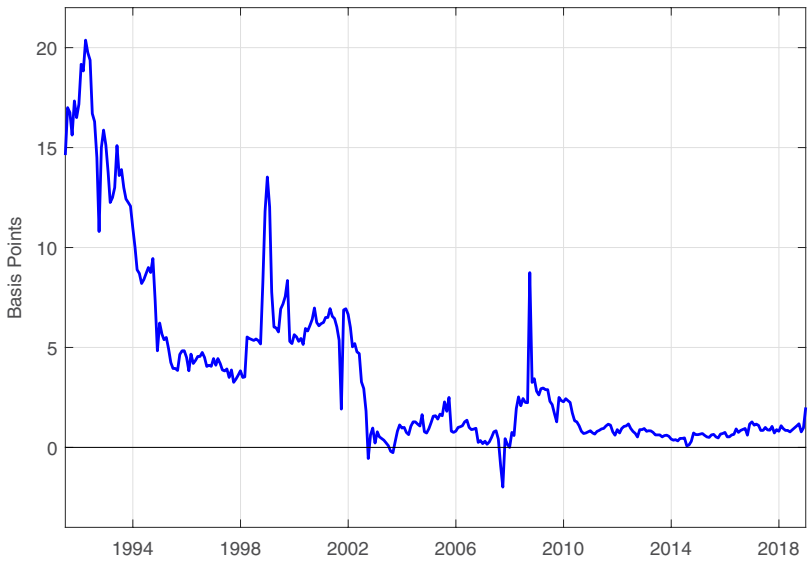

Figure 7
Turn-of-the-year premium
This figure plots the time series of the index of the turn-of-the-year premium in eurodollar futures prices.

Table 6
Regression tests for the turn-of-the-year Libor premium effect

Variable	Coefficient	t-stat	Coefficient	t-stat
Funding basis$_{t-1}$	0.25619	2.92***	0.00946	0.10
Δ turn-of-the-year premium$_t$	17.99719	2.87***	13.68621	2.09**
Fixed effects for month		Yes		Yes
Fixed effects for year		No		Yes
Adj. R^2		.176		.276
N		331		331

This table reports the results from regressions of the funding basis on its lagged value and the contemporaneous change in the turn-of-the-year Libor premium estimated from Eurodollar futures contracts. The funding basis and the turn-of-the-year Libor premium are measured in basis points. The regression is estimated with fixed effects for month of the year and fixed effects for individual years. The t-statistics are based on the Newey-West (1987) heteroscedasticity and autocorrelation consistent estimate of the covariance matrix. The sample period is monthly from June 1991 to December 2018. $*p < .1$; $**p < .05$; $***p < .01$.

basis and institutional balance sheet usage. Rather, if the funding basis is driven by balance sheet usage costs, then changes in the funding basis may contain information about changes in these costs. In this situation, changes in the funding basis essentially become an instrument for variation in balance sheet usage costs which, in turn, could clearly have causal effects on intermediary balance sheet usage.

Intuitively, we would expect that as it becomes more expensive for financial institutions to own financial assets, they would tend to reduce their holdings of

Table 7
Results from regressions of percentage changes in broker-dealer holdings of Treasury and agency bonds and total financial assets on changes in the funding basis and the turn-of-the-year premium

	Treasury and agency bonds		Total financial assets	
Variable	Coefficient	t-stat	Coefficient	t-stat
Lagged dependent variable$_{t-1}$	0.0216	0.17	0.2507	3.40**
Δ turn-of-the-year premium$_{t-1}$	0.4407	1.15	−0.1403	−0.53
Δ turn-of-the-year premium$_{t-2}$	−0.2855	−0.53	−0.7393	−1.76*
Δ turn-of-the-year premium$_{t-3}$	−0.3803	−0.98	−0.4462	−1.33
Δ funding basis$_{t-1}$	−0.0105	−1.09	−0.0140	−2.29**
Δ funding basis$_{t-2}$	−0.0204	−1.79*	−0.7393	−1.47
Δ funding basis$_{t-3}$	−0.0116	−0.98	−0.0021	−0.14
Fixed effects for quarter		Yes		Yes
Adj. R^2		.468		.192
N		110		110

This table reports the results from regressing percentage changes in the indicated broker-dealer holdings (shown in the column heading) on lagged changes in the funding spread and the turn-of-the-year premium. The funding basis and the turn-of-the-year premium are measured in basis points. We allow for quarterly fixed effects by including dummy variables that take a value of one for the first, second, third, and fourth quarters, respectively, and zero otherwise. The t-statistics are based on the Newey-West (1987) heteroscedasticity and autocorrelation consistent estimate of the covariance matrix (three lags). The sample period is quarterly from June 1991 to December 2018. $*p < .1$; $**p < .05$; $***p < .01$.

these assets on their balance sheets. To examine this hypothesis, we collect data on the total financial assets held by broker-dealers from the flow of funds data reported by the Federal Reserve Board. We note that financial assets represent the vast majority of the balance sheet assets held by broker-dealers. As an alternative measure, we also collect data on gross broker-dealer Treasury and Agency bond positions (both long and short) from the same source.[24]

Prices and quantities are jointly determined in equilibrium, so specifying the regression in a way that mitigates the potential effects of endogeneity on the results is an important step. Accordingly, we test whether changes in balance sheet usage costs—as proxied by changes in the funding basis—are associated with subsequent (rather than contemporaneous) changes in both of the broker-dealer balance sheet usage measures. Specifically, we regress quarterly changes in each of the broker-dealer measures on lagged changes in that measure and in the funding basis. We also include quarter-of-the-year fixed effects as a control in the regression.

Table 7 reports the regression results. As shown, the results provide solid support for the hypothesis that changes in the funding basis reflect variation in balance sheet usage costs, and that variation in these costs has real effects on financial intermediaries. In particular, even after controlling for lagged changes in the dependent variables, lagged changes in the funding basis have

[24] We use gross Treasury and Agency bond positions, because broker-dealers typically intermediate using "matched-book" repo transactions in which a repo position is matched with another reverse-repo position. Matched-repo intermediation is a balance-sheet-expanding activity and has become more costly as a result of Basel III supplementary leverage ratio requirements (C.F.R. 217.10(c)(4)(ii)(A), (F)).

significant predictive power for changes in the amount of financial assets and Treasury/Agency securities held by broker-dealers. Specifically, the first lagged change in the funding basis is negative and significant in the regression for changes in total financial assets. The second lagged change in the funding basis is negative and significant (at the 10% level) in the regression for changes in Treasury and Agency bond holdings. These results are intuitive and consistent with a scenario in which an increase in balance sheet usage costs both increases the funding basis and negatively affects the investment decisions and market-making activities of financial intermediaries.

7. Debt Overhang Costs and the Funding Basis

The results indicate a significant funding basis throughout most of the 1991–2018 study period that is linked to the cost of balance sheet usage by financial intermediaries. An immediate implication of this is that the balance sheet constraints imposed by post-crisis capital regulation cannot be the sole source of balance sheet usage costs or the only explanation for the persistent mispricing of derivatives relative to the underlying securities over the entire study period.

A number of important recent papers argue that debt overhang costs may represent a large component of the total costs faced by financial intermediaries in placing assets on their balance sheet. Key examples include Duffie (2018) and Andersen, Duffie, and Song (2019). Motivated by this literature, we explore the relation between debt overhang costs and the funding basis in this section.[25]

As discussed in Myers (1977), Duffie (2018), Andersen, Duffie, and Song (2019), and others, debt overhang costs reflect a potential transfer of wealth from existing shareholders to debtholders when firms acquire new assets. The reason for the transfer of wealth is simply that the new assets reduce the riskiness of the existing debt, because debtholders have a priority claim in financial distress. The riskier the existing debt, the greater the potential debt overhang problem. In light of this last point, we first use several variables suggested by the literature on structural credit modeling to proxy for the riskiness of financial sector debt which, in turn, reflects the magnitude of the potential debt overhang costs facing intermediaries.

Standard structural credit models of risky corporate debt, such as those of Merton (1974), Black and Cox (1976), and Longstaff and Schwartz (1995), among others, are based on a framework in which corporate debt is modeled as a contingent claim on the underlying assets of the firm. These models share a number of implications for the riskiness of corporate debt. In particular, these models imply that the risk of corporate debt is inversely related to the value of the firm's stock, and directly related to the volatility of stock returns. A structural model, such as Longstaff and Schwartz (1995), that allows for

[25] Section A.7 of the Internet Appendix includes a more detailed discussion of the debt overhang literature.

Table 8
Results from regressions of the funding basis on debt overhang variables

Variable	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat
Intercept	92.6051	3.77***	53.3936	8.26***	52.6045	8.22***	51.6876	8.78***
Funding basis$_{t-1}$	0.2954	−5.57***	0.3043	3.99***	0.3168	4.25***	0.3182	4.41***
Stock return$_t$	−0.3822	−1.77*	–	–	–	–	–	–
Δ Libor rate$_t$	−0.8737	−2.97***	–	–	–	–	–	–
Δ 10-year rate$_t$	0.4211	1.88*	–	–	–	–	–	–
Δ VIX$_{t-1}$	1.7948	1.98**	–	–	–	–	–	–
Δ IG Fin spread$_t$	–	–	−0.1197	−0.59	–	–	–	–
Δ IG Fin spread$_{t-1}$	–	–	0.4618	1.82*	–	–	–	–
Δ AAA spread$_t$	–	–	–	–	−0.4701	−1.54	–	–
Δ AAA spread$_{t-1}$	–	–	–	–	0.9081	2.19**	–	–
Δ BBB spread$_t$	–	–	–	–	–	–	−0.4765	−1.64
Δ BBB spread$_{t-1}$	–	–	–	–	–	–	0.7873	2.06**
End-of-quarter fixed effects		Yes		Yes		Yes		Yes
Adj. R^2		.236		.155		.158		.169
N		331		331		331		331

This table reports the results from regressions of the funding basis on its lagged value and debt overhang variables. The funding basis is measured in basis points. Stock return refers to the return on the S&P index of bank stocks (without dividends) measure over the previous 6 months and is expressed as a percentage. Libor is the 3-month Libor rate and is expressed in basis points. Ten-year is the 10-year Treasury rate and is expressed in basis points. VIX refers to the VIX index of implied volatility for the S&P 500. IG fin spread refers to the basis point spread between the yields on investment grade financial bonds and the 10-year Treasury rate. AAA spread and BBB spread refer to the Basis point spread between the yields on AAA and BBB corporate bonds and the 10 -year Treasury rate, respectively. The t-statistics are based on the Newey-West (1987) heteroscedasticity and autocorrelation consistent estimate of the covariance matrix. The sample period is monthly from June 1991 to December 2018. $^*p < .1$; $^{**}p < .05$; $^{***}p < .01$.

stochastic interest rates also implies that the risk of corporate debt is inversely related to the level and slope of the term structure. The reason for this is that the return on a firm's assets equals the risk-free rate in a risk-neutral valuation framework. Thus, an increase in the risk-free rate or slope of the term structure implies higher expected future asset values. Finally, by definition, the risk of corporate debt is directly related to its credit spread.

To explore whether variation in the funding basis can be explained by variables proxying for the potential debt overhang problems facing financial intermediaries, we regress the funding basis on its lagged value and the returns on the S&P index of bank stocks, changes in the VIX index, changes in 3-month Libor, and changes in the 10-year Treasury rate. The regression also includes end-of-the-quarter fixed effects. Table 8 reports the regression results.

The results provide strong support for the hypothesis that the funding basis is directly related to the debt overhang costs faced by financial intermediaries. In particular, each of the structural credit variables is significant. The coefficient for the return on the S&P Bank Stock index is negative and significant (at the 10% level), indicating that the funding basis decreases when the financial sector is better capitalized. The coefficient for the change in the VIX is positive and significant, indicating that the funding basis increases when stocks and, by extension, underlying corporate assets become more volatile. The coefficient

for the change in the Libor rate is negative and significant. The coefficient for the change in the 10-year rate is significant (at the 10% level) although the sign is positive.

It is important to acknowledge, however, that while finding evidence of a relation between the funding basis and the return on bank stocks and the VIX index provides support for the debt overhang hypothesis, it does not necessarily mean that other types of balance sheet constraints are precluded. For example, the relation between the funding basis and the VIX also could be consistent with the presence of regulatory constraints on value at risk. Similarly, the relation between the funding basis and bank stock returns is also consistent with He and Krishnamurthy (2012, 2013) in which the most-severe intermediation frictions occur when the intermediary is poorly capitalized.[26]

As an alternative approach, we also examine the relation between the funding basis and a number of reduced-form measures of corporate credit risk. Specifically, Table 8 also reports the results from regressing the funding basis on its lagged value and changes in three corporate bond credit spread indexes: the spread for investment grade financial sector bonds, the spread for AAA-rated corporate bonds, and the spread for BBB-rated corporate bonds. The results in Andersen, Duffie, and Song (2019) imply that credit spreads and debt overhang costs should be directly related. As shown in Table 8, the first lagged value of the change in the credit spread is significantly (at either the 5% or 10% levels) and positively related to the funding basis in all three of the reduced-form specifications. This again provides support for the hypothesis that the funding basis is related to the debt overhang costs faced by financial intermediaries.

8. Capital Regulation and the Funding Basis

Although our results imply that post-crisis regulation cannot fully explain the mispricing of derivatives relative to the underlying securities, it is still important to consider the impact of capital regulation. In this section, we focus on the relation between the funding basis and a number of capital and equity ratios that play central roles not only in the current regulatory environment but also in earlier periods, such as the 1990s, when Basel I and the Federal Deposit Insurance Corporation Improvement Act (FDICIA) were enacted.

Although our results imply that post-crisis regulation cannot fully explain the mispricing of derivatives relative to the underlying securities, it is still important to consider the impact of capital regulation. In this section, we focus on the relation between the funding basis and a number of capital and equity ratios that play central roles not only in the current regulatory environment but also in earlier periods, such as the 1990s, when Basel I and the Federal Deposit Insurance Corporation Improvement Act (FDICIA) were enacted. This

[26] We are grateful to the referee for these insights.

set of ratios should measure the impact of regulation, such as the SLR and LCR, on balance sheet usage costs more consistently throughout our entire sample than measures enacted after the financial crisis.[27] Furthermore, financial institutions that appear too leveraged are always at risk for downgrades by credit rating agencies, or may face higher margin requirements and haircuts from their counterparties. Thus, financial institutions face both explicit and implicit capital requirements.

We include four key capital and equity ratios in our analysis. Specifically, we select capital ratios based on Tier 1 capital, total capital, and equity capital because these variables were key components of capital regulation starting with the Basel I framework and the FDICIA in the early 1990s, almost two decades before the set of rules introduced in the wake of the financial crisis. The first is the Tier 1 Capital Ratio which is defined as total Tier 1 capital as a percentage of total risk-weighted assets. Second is the Core Capital Ratio which is defined as total Tier 1 capital as a percentage of average total assets minus ineligible intangibles. Third is the Equity Ratio which is defined as total equity capital as a percentage of total assets. Fourth, the Total Capital Ratio is defined as total risk-based capital as a percentage of risk-weighted assets. All of these capital ratios are quarterly averages over all banks or broker-dealers and are obtained from either the FDIC or the Z.1 flow of funds data from the Federal Reserve Board.

We acknowledge that in using these ratios, we are relying on the assumption that changes in actual capital reflect changes in required capital. This assumption, however, seems plausible, because financial institutions have strong incentives to leverage their balance sheets. Thus, increases in capital ratios are likely driven by tighter regulatory capital requirements. The tighter the requirements, the higher is the potential cost of adding additional assets to the balance sheet of a financial intermediary. Thus, we would expect to see a positive relation between capital ratios and the funding basis.

Table 9 reports the results from regressing the funding basis (averaged over the quarter) on lagged changes in the individual capital ratios. As before, we include the lagged dependent variable to control for time series effects. We also use fixed effects by quarter of the year to control for potential seasonality.[28] The regressions are estimated at a quarterly frequency.

The regression results uniformly show that the funding basis increases as financial institutions are required to hold additional capital. In particular, the coefficient for the first lagged change in the capital ratio is positive and significant in each of the four regressions. Furthermore, the magnitudes of

[27] Financial institutions continuously faced varying types of capital regulation throughout our extended sample period. Section A.8 of the Internet Appendix presents an extensive discussion of capital regulation during both the pre-crisis and post-crisis periods.

[28] Specifically, we include a dummy variable that equals one for the first quarter, and zero otherwise, a dummy variable that equals one for the second quarter, and zero otherwise, etc.

Table 9
Results from regressions of the funding basis on changes in capital ratios

Variable	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat	Coefficient	t-stat
Funding basis$_{t-1}$	0.1539	1.60	0.1561	1.60	0.1532	1.76*	0.1545	1.59
Δ Tier 1 ratio$_{t-1}$	17.1429	2.07**	–	–	–	–	–	–
Δ Tier 1 ratio$_{t-2}$	−2.1176	−0.44	–	–	–	–	–	–
Δ Tier 1 ratio$_{t-3}$	4.0309	0.78	–	–	–	–	–	–
Δ core ratio$_{t-1}$	–	–	25.3665	4.61***	–	–	–	–
Δ core ratio$_{t-2}$	–	–	−5.9527	−0.88	–	–	–	–
Δ core ratio$_{t-3}$	–	–	9.3448	2.08**	–	–	–	–
Δ equity ratio$_{t-1}$	–	–	–	–	32.1093	4.46***	–	–
Δ equity ratio$_{t-2}$	–	–	–	–	−8.0064	−0.82	–	–
Δ equity ratio$_{t-3}$	–	–	–	–	14.3830	3.14***	–	–
Δ total capital ratio$_{t-1}$	–	–	–	–	–	–	12.7331	2.95***
Δ total capital ratio$_{t-2}$	–	–	–	–	–	–	−1.5120	−0.50
Δ total capital ratio$_{t-3}$	–	–	–	–	–	–	3.7248	1.40
Fixed effects for quarter		Yes		Yes		Yes		Yes
Adj. R^2		−.003		.009		.044		.001
N		110		110		110		110

This table reports the results from regressions of the funding basis on its lagged value and on lagged changes in capital ratios. The funding basis is measured in basis points. Tier 1 ratio represents Tier 1 capital as a percentage of risk-weighted assets. Core ratio represents Tier 1 capital as a percentage of average total assets minus ineligible intangibles. Equity ratio represents total equity capital as a percentage of total assets. Total capital ratio represents total risk-based capital as a percentage of risk-weighted assets. The four capital ratios are averages over banks with total assets in excess of $10 Billion using data provided by the FDIC. We allow for quarterly fixed effects by including dummy variables that take a value of one for the first, second, third, and fourth quarters, respectively, and zero otherwise. The t-statistics are based on the Newey-West (1987) heteroscedasticity and autocorrelation consistent estimate of the covariance matrix. The sample period is quarterly from June 1991 to December 2018. $^*p < .1$; $^{**}p < .05$; $^{***}p < .01$.

the coefficients are economically significant. For example, an increase in the Tier 1 capital ratio of 1 percentage point (say from 5% to 6%) translates into an increase of 17.14 basis points in the estimated funding basis over the subsequent quarter. These results are all consistent with the hypothesis that requiring intermediaries to hold more capital increases the cost of using their balance sheets which, in turn, increases the cost of renting balance sheet space in the derivatives market.

Finally, we also explore the relation between the funding basis and several measures of systemic risk that have been put forward in the literature.[29] In particular, we regress the funding basis on its lagged value and on the Brownlees and Engle (2017) conditional shortfall measure of systemic risk, the Acharya et al. (2016) marginal expected shortfall measure of systemic risk, and the Adrian and Brunnermeier (2016) CoVaR measure of systemic risk. Table A5 of the Internet Appendix reports the regression results. These results show a significant positive relation between the funding basis and each of these three measures of systemic risk. This intuitive result implies that derivatives mispricing increases at times when intermediary capital is scarce and the lack of loss absorption capacity creates systemic risk.

[29] We are grateful to John Sedunov for this suggestion.

9. Other Derivatives Markets

This paper argues that the cost of renting intermediary balance sheet space may be a key factor in explaining the apparent mispricing of derivatives relative to the underlying securities in many markets. So far, we have studied the funding basis between the implied repo rate in Treasury note futures and the repo rate for Treasury notes. In this section, we broaden our focus by considering whether the cost of balance sheet usage affects the basis between derivatives and the underlying securities in other major derivatives markets.[30]

9.1 Interest rate swap spreads

After the interest rate futures market, the interest rate swap market is likely the next largest derivatives market in terms of daily trading volume. As discussed earlier, the average daily turnover volumes during 2016 in the interest rate futures market and interest rate swap market averaged $5.046 trillion and $1.859 trillion, respectively. While the total notional amount of interest rate swaps is estimated by the Bank for International Settlements (BIS) at $289.103 trillion at the end of 2016, it is important to recognize that this amount is not netted. In contrast, the total notional amount of interest rate futures as measured by open interest was $25.944 trillion at the end of 2018, but is based on netted values, because futures contracts are centrally cleared by futures exchanges. Thus, whether the netted notional amount of interest rate swaps actually exceeds that of interest rate futures is unclear.[31]

As shown in Duarte, Longstaff, and Yu (2007) and others, receiving fixed in an interest rate swap is effectively a synthetic position in a fixed rate bond. Thus, abstracting from Libor and swap counterparty credit risk issues, the spread between swap rates and Treasury yields—known as the swap spread—may also include the cost of renting balance sheet space from financial intermediaries (see Jermann 2019; Klingler and Sundaresan 2019). Duarte, Longstaff, and Yu (2007) document a swap spread basis that averaged roughly 20–40 basis points during their sample period.

To explore the relation between swap spreads and the cost of balance sheet usage, we first collect data on swap spreads from the Bloomberg system. We then regress changes in swap spreads for maturities ranging from 2 to 10 years on the contemporaneous and lagged change in the turn-of-the-year premium proxy for the cost of balance sheet usage. In this regression, we include the lagged change in the dependent variable as a control for time-series effects. We also include the contemporaneous and lagged changes of the funding basis.

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30 Previous research documenting commonality in mispricing includes Fleckenstein, Longstaff, and Lustig (2014), Pasquariello (2014), Lewis, Longstaff, and Petrasek (2018), and Du, Tepper, and Verdelhan (2018). In a later study, Boyarchenko et al. (2018) study whether post-crisis regulation creates a common factor in the mispricing observed in a number of markets.

31 The BIS argues that notional amounts in over-the-counter (OTC) markets are less meaningful, because positions are typically offset by entering into a new contract, which increases the notional amount. In contrast, offsetting positions in exchange traded markets are canceled. See https://www.bis.org/publ/qtrpdf/r_qt1509e.pdf#page=9.

Table 10 reports the regression results. As shown, changes in the turn-of-the-year premium are significantly related to changes in swap spreads for all five of the maturities. We also note a significant negative relation (at either the 5% or 10% level) between changes in swaps spreads and the lagged change in the turn-of-the-year premium for the 2-, 5-, and 10-year maturities. These results provide support for the hypothesis that balance sheet rental costs may affect the basis between synthetic and cash positions in multiple markets. In particular, these results indicate that variation in the cost of balance sheet usage is related to both contemporaneous and future changes in swap spreads.

9.2 Violations of CIP

The important recent paper by Du, Tepper, and Verdelhan (2018) documents the presence of significant violations of the CIP relation during the post-crisis period in many major foreign currency markets. They show that the violation of the CIP relation can be expressed as a difference between the implied funding rate in a foreign exchange forward contract and the spread between the local and foreign risk-free rates. Thus, violations of CIP can be directly interpreted as a basis between financing rates in the cash markets and a derivatives market.

As shown by Du, Tepper, and Verdelhan (2018), foreign currency markets are among the very largest markets in the world. The BIS estimates that the average daily turnover in the OTC foreign exchange forward market during 2016 was $0.700 trillion. The total notional amount of outstanding outright foreign exchange forward and swap contracts at the end of 2016 was $44.226 trillion. While this notional amount is not based on netted values, these markets are clearly very large.

To explore the relation between the balance sheet rental costs and violations of the CIP relation, we use the time-series index of 3-month CIP violations presented by Du, Tepper, and Verdelhan (2018), whose sample covers the period from 2000 to 2016. In particular, we regress the quarterly change in the value of this time series on the contemporaneous and first two lagged changes in the turn-of-the-year premium proxy for the cost of renting intermediary balance sheet space. In this regression, we include two lagged changes in the dependent variable as controls for the time-series properties of the CIP estimates. We also include the contemporaneous and first two lagged changes in the funding basis. We use quarterly changes in the regression to mitigate the potential effects of noise in the estimated changes from slight timing differences in the data or other sources.

The first panel in Table 11 presents the regression results. The table illustrates a significant positive relation between CIP violations and the turn-of-the-year premium. This result complements and extends the work of Du, Tepper, and Verdelhan (2018), who find a significant relation between CIP violations and the proximity of the end of the quarter. Our results provide additional support for the hypothesis that CIP violations may reflect the cost of renting intermediary balance sheet space.

Table 10
Results from regressions of changes in swap spreads on changes in the turn-of-the-year premium

	$N=2$		$N=3$		$N=4$		$N=5$		$N=10$	
Variable	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat
Intercept	−0.0855	−0.33	−0.1163	−0.42	−0.1189	−0.43	−0.1002	−0.40	−0.1180	−0.50
Δ N-year swap spread$_{t-1}$	0.2032	2.62***	0.1138	1.13	0.0959	1.12	0.1450	2.05**	0.2119	2.58***
Δ turn-of-the-year premium$_t$	1.1138	2.47***	0.9277	2.14**	1.0595	2.56***	1.1598	2.35***	0.6900	1.75*
Δ turn-of-the-year premium$_{t-1}$	−1.1103	−1.76*	−0.8077	−1.48	−0.9035	−1.60	−1.1549	−2.20**	−0.8099	−2.04**
Δ funding basis$_t$	−0.0063	−0.90	−0.0079	−1.26	−0.0021	−0.38	0.0027	0.56	−0.0043	−0.84
Δ funding basis$_{t-1}$	0.0046	0.82	−0.0029	−0.58	−0.0013	−0.27	−0.0007	−0.12	0.0067	1.32
Adj. R^2	.059		.017		.010		.038		.057	
Number	331		331		331		331		331	

This table reports the results from individual regressions of changes in the N-year swap spread (for the value of N shown in the column heading) on its lagged value, and on the contemporaneous and lagged change in the the turn-of-the-year premium and the funding basis. Swap spreads, the turn-of-the-year premium, and the funding basis are measured in basis points. The t-statistics are based on the Newey-West (1987) heteroscedasticity and autocorrelation consistent estimate of the covariance matrix (five lags). The sample period is monthly from June 1991 to December 2018. $^*p < .1$; $^{**}p < .05$; $^{***}p < .01$.

Table 11
Results from regressions of changes in arbitrage/basis on changes in the turn-of-the-year premium

	CIP		Dollar roll		CDS-bond basis		Treasury-TIPS arb.	
Variable	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat	Coeff	t-stat
Intercept	1.3049	1.11	2.2327	0.20	0.2887	0.54	−0.1769	−0.02
Δ dependent variable$_{t-1}$	−0.1492	−1.43	−0.6206	−3.23***	0.4150	4.48***	−0.1315	−1.09
Δ dependent variable$_{t-2}$	−0.4294	−2.29**	−0.1169	−0.84	−0.5179	−2.88***	−0.3670	−2.89***
Δ turn-of-the-year premium$_t$	3.0879	2.37***	20.3243	2.03**	1.9400	1.30	24.5659	1.59
Δ turn-of-the-year premium$_{t-1}$	−0.6446	−0.32	0.4605	0.09	−1.0054	−0.83	−12.9969	−0.76
Δ turn-of-the-year premium$_{t-2}$	2.5722	2.04**	5.5319	2.19**	6.0944	2.62***	51.2237	2.32**
Δ funding basis$_t$	0.0019	0.12	−0.1412	−1.03	−0.0466	−1.78*	−0.4923	−1.72*
Δ funding basis$_{t-1}$	−0.0111	−0.42	−0.2808	−1.32	−0.0064	−0.52	−0.1164	−0.60
Δ funding basis$_{t-2}$	−0.0466	−1.88*	−0.1530	−1.15	−0.0090	−0.85	−0.2507	−1.77*
Adj. R^2	.179		.221		.506		.461	
Number	68		60		44		29	

This table reports the results from individual regressions of quarterly changes in the indicated arbitrage or basis on its lagged value and on contemporaneous and lagged changes in the turn-of-the-year premium and the funding basis. The turn-of-the-year premium and the funding basis are measured in basis points. The t-statistics are based on the Newey-West (1987) heteroscedasticity and autocorrelation consistent estimate of the covariance matrix. $^*p < .1$; $^{**}p < .05$; $^{***}p < .01$.

9.3 Dollar roll specialness

In an insightful recent paper, Song and Zhu (2019) show that the implied funding rate incorporated into forward contracts in the mortgage-backed security market (TBA contracts) differs from the repo rate for the underlying securities. This difference—which they denote dollar roll specialness—represents another important example of a funding-related basis between cash market securities and their derivative counterparts. As discussed by Song and Zhu (2019), the agency mortgage-backed securities market is one of the very largest of all fixed income markets. The Securities Industry and Financial Markets Association (SIFMA) estimates the total outstanding amount of agency mortgage-backed securities at the end of 2016 to be $6.530 trillion. Furthermore, daily trading volumes in the cash and forward (TBA) mortgage-backed securities markets are very large. For example, SIFMA estimates the daily trading volume in the agency TBA market during 2016 to be $0.209 trillion.

We use the time series of dollar roll specialness for the closest-to-par mortgage-backed securities provided in Song and Zhu (2019) to explore its commonality with the funding basis. Note, however, that we reverse its sign in order to be consistent with our interpretation of the basis as the implied derivatives rate minus the cash market financing rate. This time series covers the period from 1998 to 2013. The second panel in Table 11 reports the results from regressing changes in dollar roll specialness on its lagged value and on contemporaneous and lagged changes in the turn-of-the-year premium and the funding basis.

The regression results show a significant relation between dollar roll specialness and the turn-of-the-year premium. In particular, the contemporaneous

and second lagged changes in the turn-of-the-year premium are significantly positively related to changes in the dollar roll specialness index. Again, this provides support for the hypothesis that funding-related bases between cash market securities and their derivative counterparts may reflect the cost of renting intermediary balance sheet space.

9.4 The corporate bond/CDS basis

An extensive literature documents the presence of a significant basis between the yields of corporate bonds and CDS spreads. Examples include Longstaff, Mithal, and Neis (2005), Blanco, Brennan, and Marsh (2005), Duffie (2010), and Bai and Collin-Dufresne (2019), among others. The U.S. corporate bond market is one of the largest fixed income markets in the world with a total outstanding amount estimated by SIFMA to be $8.701 trillion as of the end of 2016. Since its inception, the CDS market has also grown rapidly. The total notional size of the CDS market at the end of 2016 is estimated by the BIS to be $9.931 trillion. As with interest rate swaps, however, this notional amount is not netted.

To study the commonality with the funding basis, we use the corporate bond/CDS basis time series provided in Du, Tepper, and Verdelhan (2018) which covers the 2005 to 2016 period. We again regress changes in this basis on its lagged value and on contemporaneous and lagged changes in the turn-of-the-year premium and the funding basis. The third panel of Table 11 reports the regression results.

As shown, the results again provide support for the hypothesis about the effect of balance sheet rental costs on pricing in the derivatives markets. Specifically, the second lagged change in the turn-of-the-year premium is positively and significantly related to the change in in the CDS-bond basis.

9.5 The Treasury-TIPS arbitrage

One of the most important innovations in fixed income markets in the past several decades was the introduction of Treasury inflation-protected securities (TIPS) in 1997. The total notional amount of TIPS outstanding at the end of 2018 was $1.413 trillion. In a recent paper, Fleckenstein, Longstaff, and Lustig (2014) show that inflation swaps can be combined with Treasury TIPS to create synthetic nominal bonds. They show a significant basis between actual Treasury bonds and their synthetic counterparts. Furthermore, Fleckenstein, Longstaff, and Lustig (2014) show that this basis is correlated with the basis between corporate bonds and CDS contracts, as well as with the basis between the CDX CDS index and its 125 individual CDS components.

To explore the commonality between the funding basis and the Treasury-TIPS arbitrage, we construct an updated version of the data set in Fleckenstein, Longstaff, and Lustig (2014). This data set provides estimates of the Treasury-TIPS arbitrage for the period from July 2004 to September 2011. Following a similar approach as in previous sections, we regress monthly changes

in the arbitrage on lagged changes of the dependent variable, and on the contemporaneous and lagged changes in the turn-of-the-year premium and the funding basis. The fourth panel of Table 11 reports the regression results.

Paralleling earlier results, the regression provides evidence of a positive relation between the Treasury-TIPS arbitrage and the turn-of-the-year premium. In particular, the coefficient for the second lagged change in the turn-of-the-year premium is positive and significant.

9.6 Summary

Taken together, the results in Tables 10 and 11 support the hypothesis that the cost of renting intermediary balance sheet space drives a wedge between the pricing of derivatives and the underlying securities in a number of the largest financial markets. While these results are statistically significant, however, we also need to acknowledge that the results clearly do not suggest that our proxy for balance sheet rental costs explains the majority—or even a large portion—of these bases. Thus, our results should be interpreted with an appropriate degree of caution. Nevertheless, we view the exploration of the effects of balance sheet rental costs on different asset classes and/or markets as an important direction for future research.

10. Conclusion

An extensive literature dating back more than 30 years shows that the implicit funding rates in derivative contracts often diverge from riskless rates observed in the cash markets. This paper presents evidence that the costs of renting balance sheet space from financial intermediaries may help resolve this puzzle.

We study the funding basis between Treasury note futures and Treasury notes and show that it is directly linked to proxies for the cost of intermediary balance sheet usage, such as the quarter-end effect and the turn-of-the-year premium, in the Libor market. We find that this balance sheet link is present throughout the 1991–2018 sample period and is not simply an artifact of post-crisis capital regulation. These results indicate that the important results in Du, Tepper, and Verdelhan (2018) generalize to other large derivatives markets and apply to extended periods predating the 2008 financial crisis.

The results also provide support for recent theory about the impact of financial intermediaries on asset pricing. Consistent with Duffie (2018), we find that the funding basis is directly related to proxies for the size of the debt overhang problem faced by financial intermediaries in placing additional assets on their balance sheets. The funding basis is also related to the amount of capital financial intermediaries are required to hold. Finally, we show that our results extend to the bases observed between securities and their derivative/synthetic counterparts in a number of the largest derivatives markets. In particular, many of these bases are also significantly related to the turn-of-the-year instrument for the cost of renting intermediary balance sheet space.

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