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The TIPS-Treasury Bond Puzzle

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ABSTRACT

We show that the price of a Treasury bond and an inflation-swapped Treasury Inflation-Protected Securities (TIPS) issue exactly replicating the cash flows of the Treasury bond can differ by more than $20 per $100 notional. Treasury bonds are almost always overvalued relative to TIPS. Total TIPS-Treasury mispricing has exceeded $56 billion, representing nearly 8% of the total amount of TIPS outstanding. We find direct evidence that the mispricing narrows as additional capital flows into the markets. This provides strong support for the slow-moving-capital explanation of arbitrage persistence.

THE TREASURY BOND and the Treasury Inflation-Protected Securities (TIPS) markets are two of the largest and most actively traded fixed-income markets in the world. Despite this, we find that there is persistent mispricing on a massive scale across these two markets. Furthermore, this mispricing is almost invariably in one direction—Treasury bonds are consistently overpriced relative to TIPS. For example, we show that the price of a Treasury bond can exceed that of an inflation-swapped TIPS issue exactly matching the cash flows of the Treasury bond by more than $20 per $100 notional amount. The relative mispricing of TIPS and Treasury bonds represents one of the largest examples of arbitrage ever documented and poses a major puzzle to classical asset pricing theory.[1]

We proceed by first describing the TIPS-Treasury arbitrage strategy. The logic behind this strategy is simple. The inflation-linked cash flows from a

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[1] For examples of significant mispricing in other financial markets, see Dammon, Dunn, and Spatt (1993) and Lamont and Thaler (2003).

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TIPS issue can be converted into fixed cash flows using inflation swaps. The resulting cash flows can be structured to match exactly the cash flows from a Treasury bond with the same maturity date as the TIPS issue. Hence, we have created a synthetic nominal Treasury bond from the TIPS issue. Price differences between the synthetic Treasury bond and the nominal Treasury bond therefore represent straightforward arbitrage opportunities. The data set includes daily prices for 29 maturity-matched pairs of TIPS issues and Treasury bonds from 2004 to 2009.

We find mispricing across all pairs of TIPS and Treasury bonds. For individual pairs, the mispricing often exceeds \$10 to \$20.[2] Translated into yields, the average size of the mispricing is 54.5 basis points, but can exceed 200 basis points for some pairs. The average size of this mispricing is orders of magnitude larger than the transaction costs of executing the arbitrage strategy. While other instances of Treasury mispricing have been documented, these have all been much smaller in size. One prominent example is the yield spread between old and new Treasury bonds, commonly referred to as the on-the-run/off-the-run spread.[3] The TIPS-Treasury mispricing we find is much larger and more persistent than the on-the-run/off-the-run spread for Treasuries.[4]

We also provide clear evidence that our results are not simply due to mispricing in the inflation swaps market since we find no mispricing on average when the same arbitrage strategy is applied to corporate fixed-rate and inflation-linked bonds. Thus, the mispricing is directly attributable to the relative prices of TIPS and Treasury bonds—Treasuries are expensive relative to TIPS. We also consider the potential impact of transaction costs, differential taxation, credit risk, institutional and foreign ownership of Treasury bonds and TIPS, collateralization, the ability to short Treasury bonds, market liquidity, and other factors. None of these factors are able to provide a fully satisfactory explanation for the existence of this mispricing.

Is the TIPS-Treasury arbitrage strategy truly an arbitrage in the textbook sense? Or is it a risky leveraged strategy that could result in losses for an arbitrageur in some states of the world? The answer to both of these questions is yes. As shown by Shleifer and Vishny (1997), Liu and Longstaff (2005), and others, even a textbook arbitrage can generate mark-to-market losses that might force an arbitrageur facing constraints to unwind a position at a loss prior to convergence. In this paper, we distinguish between the general question of whether arbitrage mispricing exists and the specific question of whether a particular hedge fund could profitably implement the arbitrage strategy. We focus on the first since it depends only on market prices, and abstract from the second since it depends entirely on the idiosyncratic set of constraints faced by

[2] For simplicity, all bond prices and dollar mispricing values will be expressed in terms of dollars per \$100 notional or par amount throughout the paper.

[3] For a description of the properties of on-the-run bonds, see Krishnamurthy (2002) and Vayanos and Weill (2008).

[4] For example, Krishnamurthy (2002) finds that this spread averages 6.05 basis points for 30-year Treasuries between 1995 and 1999. Furthermore, the on-the-run/off-the-run spread typically decreases to close to zero right before auctions.

the arbitrageur. We observe, however, that many hedge funds and institutional asset managers have, in fact, implemented trading strategies that exploit the divergence between the prices of TIPS, Treasuries, and inflation swaps.

The primary objective of this paper, however, is not just to document a major violation of the law of one price in the financial markets. Rather, our goal is to also shed light on two fundamental issues in asset pricing. First, why is the mispricing there in the first place, and what accounts for its size and sign? Second, why does mispricing persist?

Turning to the first issue, previous papers argue that investors value the liquidity and safety of U.S. Treasury bonds and are willing to forgo returns as a result, likening these bonds to money (see, for example, Longstaff (2004), Bansal, Coleman, and Lundblad (2010), Krishnamurthy and Vissing-Jorgensen (2010a)). These special attributes drive down the yield on Treasury bonds relative to other similar securities not issued by the Treasury, especially when the Treasury securities are in short supply. Krishnamurthy and Vissing-Jorgensen (2010a) refer to this yield spread between Treasuries and similar non-Treasury securities as a Treasury convenience yield. Our findings suggest that only nominal securities issued by the Treasury are perceived to have these attributes, not the inflation-indexed ones. This could help explain why nominal Treasury bonds are consistently expensive relative to inflation-indexed securities issued by the Treasury, and why this differential increases during times of financial distress when demand for these attributes increases.

Turning next to the second issue of the persistent nature of mispricing, important recent theoretical work by Gromb and Vayanos (2002), Duffie (2010), Ashcraft, Gârleanu, and Pedersen (2010), Brunnermeier and Pedersen (2009), and others stresses that slow-moving capital may play a key role in propagating mispricing in financial markets. Motivated by this work, we explore the implications of the slow-moving-capital hypothesis by studying the relation between changes in TIPS-Treasury mispricing and changes in capital available to arbitrageurs. The results provide direct evidence that the mispricing narrows as additional hedge fund capital flows into the market. This novel result provides strong support for the slow-moving-capital explanation of the persistence of arbitrage mispricing in the market.

Another implication of the slow-moving-capital literature is that these types of frictions may induce correlations across different types of arbitrages. To see the intuition behind this implication, imagine that there was a large downward shock in the aggregate amount of capital available to arbitrageurs in the market. As a result, we might observe the amount of mispricing between securities widening in multiple markets simultaneously. To investigate this correlated arbitrage implication, we regress changes in TIPS-Treasury mispricing on changes in the corporate bond/CDS arbitrage described by Duffie (2010), the CDX index/component arbitrage, the on-the-run/off-the-run spread (Krishnamurthy (2002)), and the Refcorp-Treasury spread (Longstaff (2004)). Although these mispricings occur in very different markets, we find that there is strong commonality across these mispricings, consistent with the theory.

An additional implication of the slow-moving-capital literature is that changes in capital may have forecasting power for subsequent changes in mispricing. Specifically, if capital flows slowly to arbitrageurs, then an increase in capital today will tend to reduce mispricing in the market, but only with a lag. Thus, we could predict future changes in mispricing conditional on current changes in aggregate investor wealth. To explore this implication, we regress changes in TIPS-Treasury mispricing on ex-ante measures of changes in aggregate investor wealth such as stock, bond, and hedge fund returns. Consistent with theory, we find that changes in mispricing are strongly forecastable and are negatively related to these ex-ante returns. Finally, we also find that TIPS-Treasury mispricing is affected by funding liquidity factors such as the availability of Treasury collateral in the primary dealer repo market.

The results in this paper also have public finance implications. While there may be legitimate reasons for why the Treasury chooses to issue TIPS, our results imply that the Treasury faces some costly trade-offs in doing so. In particular, our results suggest that the Treasury could have saved billions of dollars by issuing nominal bonds instead of TIPS over the past decade. On average, the U.S. government has to levy $2.92 more in taxes, in present discounted value, to repay $100 of debt issued if the debt is indexed rather than nominal. Furthermore, nominal debt allows for state contingency in real returns by creating inflation. In response to an adverse fiscal shock, the government can exploit this state contingency to smooth taxes either through surprise inflation or the announcement of inflation at some point in the future before the current nominal debt matures. In contrast, indexed debt does not allow for this type of state contingency. Thus, by issuing TIPS, the government clearly gives up a valuable fiscal hedging option.

Finally, our findings of persistent arbitrage mispricing in these markets also imply that the Treasury-TIPS price differentials cannot be used to back out the market's inflation expectations, a common practice. In fact, the implied measure is biased downward, and the bias worsens in times of increased volatility in financial markets.

This paper contributes to the literature on the pricing of inflation-linked bonds. Other important papers on real bonds include Roll (1996, 2004), Barr and Campbell (1997), Evans (2003), Seppälä (2004), Bardong and Lehnert (2004), Buraschi and Jiltsov (2005), Ang, Bekaert, and Wei (2007, 2008), Campbell, Shiller, and Viceira (2009), Dudley, Roush, and Ezer (2009), Fleming and Krishnan (2009), Adrian and Wu (2009), Barnes et al. (2009), Gürkaynak, Sack, and Wright (2010), Christensen, Lopez, and Rudebusch (2010a, b), Andonov, Bardong, and Lehnert (2010), Pflueger and Viceira (2011a, b), and many others. This paper differs from the previous literature by being the first to formally study the no-arbitrage relation between TIPS and Treasury bonds and explore the determinants of the mispricing.[5]

The remainder of this paper is organized as follows. Section I provides a brief introduction to the TIPS and inflation swap markets and describes the TIPS-Treasury arbitrage strategy. Section II describes the data. Section III examines

[5] Our key findings have also been confirmed in subsequent studies. For example, see Fleckenstein (2012) and Haubrich, Pennacchi, and Ritchken (2012).

the size of the TIPS-Treasury mispricing. Section IV discusses the risks that an arbitrageur might face in implementing the strategy. Section V examines whether these results are simply an artifact of mispricing in the inflation swap market. Section VI considers additional factors that might drive a wedge between the pricing of TIPS and Treasury bonds. Section VII explores the determinants of TIPS-Treasury mispricing. Section VIII examines the relation between TIPS-Treasury mispricing and other types of arbitrage mispricing. Section IX investigates the forecastability of TIPS-Treasury mispricing. Section X summarizes the results and presents concluding remarks.

I. TIPS Treasury Arbitrage

In this section, we provide brief introductions to the TIPS and inflation swap markets. We then describe the arbitrage strategy that links the theoretical prices of Treasury bonds, TIPS, and inflation swaps.

A. The TIPS Market

TIPS are direct obligations of the U.S. Treasury and are similar in most respects to Treasury bonds.[6] The key difference is that the principal amount of a TIPS issue is adjusted over time to reflect changes in the Consumer Price Index (CPI). Since the fixed coupon rate for the TIPS issue is applied to its principal amount, the actual semiannual coupon received varies over time as the principal amount changes in response to the realized inflation or deflation rate. Similarly, the final principal amount paid to the bondholder equals the maximum of the original principal amount or the inflation-adjusted principal amount. Thus, TIPS investors' principal is protected against deflation (although the same is not true for coupon payments).

The principal amount of a TIPS issue is adjusted daily based on the CPI for All Urban Consumers, known as CPI-U. Let I_t denote the inflation adjustment for a TIPS issue as of date t. The inflation adjustment is computed as the ratio of the reference CPI at the valuation date t divided by the reference CPI at the issuance date, which we designate as time 0. The reference CPI for a particular date during a month is linearly interpolated from the CPI reference index for the beginning of that month and the CPI reference index for the beginning of the subsequent month. The CPI reference index for the first day of any calendar month is the CPI-U index for the third preceding calendar month. Thus, the reference CPI for April 1 would be the CPI-U index for the month of January, which is reported by the Bureau of Labor Statistics during February. Details on how TIPS are adjusted for inflation are described on the U.S. Treasury's website.[7]

[6] For expositional convenience, we generally refer to all nominal debt obligations of the Treasury (including Treasury bills and Treasury notes) simply as Treasury bonds throughout the paper.

[7] See http://www.treasurydirect.gov/instit/statreg/auctreg/auctreg_gsr31cfr356. pdf.

The total principal amount of all TIPS outstanding at the end of the sample period is in excess of $550 billion. The Treasury first began auctioning TIPS in January 1997. As of the end of our sample period, 34 separate TIPS issues have been auctioned. Currently, the Treasury issues 5-year, 10-year, and 30-year TIPS on a regular cycle.

B. The Inflation Swap Market

Beginning with the first TIPS auction in 1997, market participants began making markets in inflation swaps as a way of hedging inflation risk. As the TIPS market has grown, the inflation swap market has become liquid and actively traded, particularly in the United States and the United Kingdom.[8] Inflation swaps have also become widely used among institutional investment managers because of their high correlation with realized CPI.[9] The notional size of the inflation swap market is estimated by Pond and Mirani (2011) to be on the order of hundreds of billions. Conversations with inflation swap traders confirm that these instruments are fairly liquid with typical bid-ask spreads on the order of five basis points.[10]

In this paper, we focus on the most basic and widely used type of inflation swap, namely, a zero-coupon swap. This swap is executed between two counterparties at time 0 and has only one cash flow that occurs at the maturity date of the swap. For example, imagine that at time 0, the five-year zero-coupon inflation swap rate is 200 basis points. As is standard with swaps, there are no cash flows at time 0 when the swap is executed. At the maturity date of the swap in five years, the counterparties to the inflation swap exchange a cash flow of $(1 + 0.0200)^5 - I_t$, where I_t is again the inflation adjustment factor. Thus, if the realized inflation rate was 1.50% per year over the five-year horizon of the swap, $I_t = 1.015^5 = 1.077284$. In this case, the net cash flow from the swap would be $(1 + 0.0200)^5 - 1.077284 = \$0.026797$ per dollar notional of the swap. The timing and index lag construction of the index I_t used in an inflation swap are chosen to match precisely the definitions applied to TIPS issues.

C. The Arbitrage Strategy

The idea behind the TIPS-Treasury arbitrage strategy is very simple. Imagine that an investor buys a TIPS issue at par that has a coupon rate of s per semiannual period. Because of the inflation adjustment, the coupon paid at

[8] Kerkhof (2005) provides an excellent introduction to the inflation swap market. Also, see Jarrow and Yildirim (2003) and Hinnerich (2008). Fleckenstein (2012) extends our analysis to other inflation-linked bond markets including the United Kingdom.

[9] As one example, inflation swaps are a key element of J.P. Morgan's Columbus Fixed Income Inflation Managed Bond Strategy.

[10] This estimate of the bid-ask spread is consistent with Schulz and Stapf (2011), who find that the median bid-ask spreads for seven-year inflation swaps near the height of the 2008 crisis period were on the order of four to seven basis points, with a few values exceeding 10 basis points. Typical values during noncrisis periods would presumably be lower.

time t will be sI_t. Now imagine that the investor executes a zero-coupon inflation swap with a maturity date and notional amount matching that of the coupon payment for the TIPS issue. At date t, the inflation swap pays a cash flow of $s(1+f)^t - sI_t$, where f is the fixed inflation swap rate. The sum of the two cash flows is now just $sI_t + s(1+f)^t - sI_t = s(1+f)^t$, which is a constant. Similarly, by executing zero-coupon inflation swaps with maturities and notional amounts matching the indexed cash flows from the TIPS issue, the investor can convert all of these indexed cash flows into fixed cash flows.

To make the mechanics of this arbitrage strategy more clear, Table I shows the various components of the strategy and their associated cash flows. The first part of the table shows the cash flows associated with a Treasury bond purchased at price P and with a coupon rate of c. The Treasury bond pays a semiannual coupon of c per period, and then makes a principal payment of 100 at maturity date T.

The second part of the table shows how the cash flows from the Treasury bond can be replicated exactly from a TIPS position. First, the arbitrageur purchases a TIPS issue with a coupon rate of s and the same maturity date as the Treasury bond for a price of V. The TIPS bond pays coupons of sI_t each period, and then makes a principal payment of $100I_T$ at maturity. The arbitrageur then enters into an inflation swap for each coupon payment date with a notional amount of s (or $s + 100$ for the final principal payment date). This converts all of the indexed cash flows from the TIPS into fixed cash flows. To match exactly the cash flows from the Treasury bond, however, the arbitrageur also needs to go long or short a small amount of Treasury STRIPS (separate trading of registered interest and principal securities) for each coupon payment date. As shown at the bottom of the second part of the table, the net result is a portfolio that exactly replicates the cash flows from the Treasury bond in the first part of the table.[11]

To provide a specific example, Table II shows the actual cash flows that would result from applying the arbitrage strategy on December 30, 2008, to replicate the 7.625% coupon Treasury bond maturing on February 15, 2025. As shown, the price of the Treasury bond is \$169.479. To replicate the Treasury bond's cash flows, the arbitrageur buys a 2.375% coupon TIPS issue with the same maturity date for a price of \$101.225. Since there are 33 semiannual coupon payment dates, 33 inflation swaps are executed with the indicated notional amounts. Finally, positions in Treasury STRIPS of varying small notional amounts are also taken by the arbitrageur. The net cash flows from the replicating strategy exactly match those from the Treasury bond, but at a cost of only \$146.379. Thus, the cash flows from the Treasury bond can be replicated at a cost that is \$23.10 less than that of the Treasury bond.

[11] There are alternative ways in which some parts of the arbitrage strategy could be implemented. For example, an investor could enter into an asset swap as an alternative to taking a position in a Treasury bond or TIPS issue directly. Asset swaps can be viewed as equivalent to taking a long position in the asset and financing the transaction at Libor plus a spread. Market participants often refer to the difference between Treasury and TIPS asset swap spreads as the breakeven inflation spread and contrast it with the inflation swap spread.

Table I

Cash Flows from the Treasury Bond and the Synthetic Treasury Bond Replicating Strategy

This table shows the cash flow generated each period from the indicated positions. P denotes the price of the Treasury bond with coupon c, V denotes the price of the TIPS bond with the same maturity date as the Treasury bond and a coupon rate of s, and $D(t)$ denotes the price of a Treasury STRIP with a maturity of t. F_t denotes the fixed payment on a zero-coupon inflation swap of maturity t (calculated as $(1+f)^t$, where f is the corresponding inflation swap rate). The inflation index I_t denotes the ratio of the CPI-U index at time t divided by the CPI-U index at time zero.

Strategy	0	1	2	3	...	T
Buy Treasury	$-P$	c	c	c	...	$c+100$
Buy TIPS	$-V$	sI_1	sI_2	sI_3	...	$(s+100)I_T$
Inflation Swap$_1$	0	$s(F_1-I_1)$	0	0	...	0
Inflation Swap$_2$	0	0	$s(F_2-I_2)$	0	...	0
Inflation Swap$_3$	0	0	0	$s(F_3-I_3)$	...	0
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
Inflation Swap$_T$	0	0	0	0	...	$(s+100)(F_T-I_T)$
STRIPS$_1$	$-(c-sF_1)D(1)$	$c-sF_1$	0	0	...	0
STRIPS$_2$	$-(c-sF_2)D(2)$	0	$c-sF_2$	0	...	0
STRIPS$_3$	$-(c-sF_3)D(3)$	0	0	$c-sF_3$	...	0
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
STRIPS$_T$	$-(c+100)D(T)-$ $(s+100)F_T D(T)$	0	0	0	...	$(c+100)-$ $(s+100)F_T$
Total Cash Flow	$\sum_{i=1}^{T}(c-sF_i)\,D(i)+$ $100(1-F_T)D(T)-V$	c	c	c	...	$c+100$

Table II

A Specific Example of the Synthetic Treasury Bond Replicating Strategy

This table shows the cash flows associated with the 7.625% Treasury bond with maturity date January 15, 2025, and the cash flows from the replicating strategy using the 2.375% TIPS issue with the same maturity date that replicates the cash flows of the Treasury bond. The example is based on market prices for December 30, 2008. Cash flows are in dollars per $100 notional. I_t denotes the realized percentage change in the CPI index from the inception of the strategy to the cash flow date. Date refers to the number of the semiannual period in which the corresponding cash flows are paid.

Date	Treasury	TIPS	Inflation Swaps	STRIPS	Total
0	−169.4793	−101.2249	0	−45.6367	−146.3786
1	3.8125	1.1875 I_1	1.1856 − 1.1875 I_1	2.6269	3.8125
2	3.8125	1.1875 I_2	1.1638 − 1.1875 I_2	2.6487	3.8125
3	3.8125	1.1875 I_3	1.1480 − 1.1875 I_3	2.6645	3.8125
4	3.8125	1.1875 I_4	1.1467 − 1.1875 I_4	2.6658	3.8125
5	3.8125	1.1875 I_5	1.1307 − 1.1875 I_5	2.6818	3.8125
6	3.8125	1.1875 I_6	1.1376 − 1.1875 I_6	2.6749	3.8125
7	3.8125	1.1875 I_7	1.1566 − 1.1875 I_7	2.6559	3.8125
8	3.8125	1.1875 I_8	1.1616 − 1.1875 I_8	2.6509	3.8125
9	3.8125	1.1875 I_9	1.1630 − 1.1875 I_9	2.6495	3.8125
10	3.8125	1.1875 I_{10}	1.1773 − 1.1875 I_{10}	2.6352	3.8125
11	3.8125	1.1875 I_{11}	1.1967 − 1.1875 I_{11}	2.6158	3.8125
12	3.8125	1.1875 I_{12}	1.2095 − 1.1875 I_{12}	2.6030	3.8125
13	3.8125	1.1875 I_{13}	1.2248 − 1.1875 I_{13}	2.5877	3.8125
14	3.8125	1.1875 I_{14}	1.2466 − 1.1875 I_{14}	2.5659	3.8125
15	3.8125	1.1875 I_{15}	1.2683 − 1.1875 I_{15}	2.5442	3.8125
16	3.8125	1.1875 I_{16}	1.2866 − 1.1875 I_{16}	2.5259	3.8125
17	3.8125	1.1875 I_{17}	1.3058 − 1.1875 I_{17}	2.5067	3.8125
18	3.8125	1.1875 I_{18}	1.3304 − 1.1875 I_{18}	2.4821	3.8125
19	3.8125	1.1875 I_{19}	1.3556 − 1.1875 I_{19}	2.4569	3.8125
20	3.8125	1.1875 I_{20}	1.3792 − 1.1875 I_{20}	2.4333	3.8125
21	3.8125	1.1875 I_{21}	1.4009 − 1.1875 I_{21}	2.4116	3.8125
22	3.8125	1.1875 I_{22}	1.4225 − 1.1875 I_{22}	2.3900	3.8125
23	3.8125	1.1875 I_{23}	1.4427 − 1.1875 I_{23}	2.3698	3.8125
24	3.8125	1.1875 I_{24}	1.4635 − 1.1875 I_{24}	2.3490	3.8125
25	3.8125	1.1875 I_{25}	1.4806 − 1.1875 I_{25}	2.3319	3.8125
26	3.8125	1.1875 I_{26}	1.4979 − 1.1875 I_{26}	2.3146	3.8125
27	3.8125	1.1875 I_{27}	1.5126 − 1.1875 I_{27}	2.2999	3.8125
28	3.8125	1.1875 I_{28}	1.5277 − 1.1875 I_{28}	2.2848	3.8125
29	3.8125	1.1875 I_{29}	1.5407 − 1.1875 I_{29}	2.2718	3.8125
30	3.8125	1.1875 I_{30}	1.5548 − 1.1875 I_{30}	2.2577	3.8125
31	3.8125	1.1875 I_{31}	1.5676 − 1.1875 I_{31}	2.2449	3.8125
32	3.8125	1.1875 I_{32}	1.5823 − 1.1875 I_{32}	2.2302	3.8125
33	103.8125	101.1875 I_{33}	135.9861 −101.1875 I_{33}	−32.1736	103.8125

To evaluate whether the arbitrage would be profitable after considering transaction costs, we obtain estimates of the bid-ask spreads for the various elements of the strategy. Fleming (2003) shows that the average cost of trading a 10-year Treasury bond is on the order of 0.78 ticks (32nds) and is rarely more than 1.5 ticks. He also shows that the cost is lower for shorter maturity Treasury notes and bonds. Fleming and Krishnan (2009) estimate that the bid-ask spreads for 5-year, 10-year, and 20-year TIPS issues are 2.6, 2.7, and 7.3 ticks, respectively. Daves and Ehrhardt (1993) estimate the average bid-ask spread for Treasury STRIPS at about three ticks. This is consistent with Grinblatt and Longstaff (2000), who provide estimates ranging from one to four ticks. Similar estimates are given in Jordan, Jorgensen, and Kuipers (2000). Finally, as described above, the average bid-ask spread for inflation swaps is estimated to be five basis points in terms of yields. We have also confirmed these estimates of transaction costs through discussions with a number of Treasury bond traders.

To provide specific estimates of the cost of implementing an arbitrage strategy similar to that shown in Table II, we do the following. First, we assume that the bid-ask spreads for Treasury bonds, TIPS, and STRIPS are two, six, and four ticks, respectively. In addition, we assume that the bid-ask spread for inflation swaps is six basis points. These values are clearly very conservative estimates (overestimates) of the actual transaction costs. Second, we apply these estimates to the strategy shown in Table II. To provide additional perspective, we also compute the transaction costs for 2-year, 5-year, and 10-year versions of the strategy in which we hold the cash flows fixed, but vary the assumed maturity date of the strategy. The estimated transaction costs for the 2-year, 5-year, 10-year, and actual strategies are approximately 20.2, 29.5, 46.3, and 69.1 cents per $100 notional amount, respectively. These transactions costs are clearly orders of magnitude smaller than the arbitrage. Thus, transaction costs cannot begin to account for mispricing of this magnitude.

The data for the study consist of daily closing prices for U.S. Treasury bonds, TIPS, STRIPS, and inflation swaps for the period from July 23, 2004, to November 19, 2009. All data are obtained from the Bloomberg system. The TIPS and Treasury pairs in the data set have maturities ranging from 2007 to 2032. Daily closing prices for TIPS and Treasury bonds are adjusted for accrued interest following standard market conventions.

Inflation swaps are quoted in terms of the constant rate on the contract's fixed leg. The traded maturities are 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 20, 25, and 30 years. To obtain swap rates for intermediate maturities, we use cubic spline interpolation. For maturities that include fractional years (e.g., 2.3 years), seasonal patterns in inflation must be taken into account. To do this, we first estimate seasonal weightings for the CPI-U for each month of the year by regressing the CPI-U index values for the January 1980 to October 2009 period on monthly indicator variables. The estimated weights are normalized to ensure that there is no seasonal effect for full-year swaps and then used to adjust the interpolated inflation swap curve (seasonal adjustments are not used for maturities less than one year). Details about the algorithm used to compute synthetic Treasury bond prices are provided in the Appendix.

For our analysis, we match TIPS and Treasury bonds based on their respective maturities. We define maturity mismatch as the number of days between the maturity of a TIPS issue and the maturity of a Treasury bond with the closest maturity to that of the TIPS issue. We only include pairs of TIPS and

Treasury bonds in the sample if the maturity mismatch is less than or equal to 31 days. This leads to a total of 29 TIPS-Treasury bond pairs.[12] In particular, there are seven exact matches, nine mismatches of 15 days, and 13 mismatches of 31 days. The 31-day mismatches occur only for maturities of February 2015 or later. Thus, these mismatches represent a very small percentage mismatch in the maturities of the TIPS and Treasury bonds. To adjust for the maturity mismatches, we calculate the yield to maturity on the synthetic fixed-rate bond formed from the TIPS issue and the inflation swaps, and then apply this yield to calculate the price of a synthetic bond that would exactly match the maturity of the Treasury bond in the pair.

Table III provides summary statistics for the mispricing for each of the 29 pairs of TIPS and Treasury bonds in the sample. The first two columns show the maturity date and coupon rate for the TIPS issue in each pair. The next two columns show the maturity date and coupon rate for the Treasury bond in each pair. The column labeled Mismatch in Days denotes the maturity mismatch between the two bonds. The central panel of the table reports summary statistics for the mispricing. The rightmost panel of the table reports summary statistics for the mispricing measured as the basis point difference between the yield of the synthetic Treasury bond and the actual Treasury bond for each pair.

The mispricing reported in Table III is stunning in magnitude and is likely the largest ever documented in any fixed-income market.[13] For example, the mispricing for many of the TIPS-Treasury pairs with maturities of 2015 or later reach values in excess of \$10. In fact, the mispricing for the TIPS-Treasury pair maturing in 2025 reaches a level in excess of \$23. What makes these findings even more dramatic is that the TIPS and Treasury markets are two of the largest and most liquid financial markets in the world. In almost every case, the value of the Treasury bond is larger than its synthetic equivalent constructed from the matching TIPS issue and the inflation swap. Thus, Treasury bonds appear to be almost uniformly "rich" relative to the portfolios of Treasury securities that replicate their cash flows.

The average sizes of the mispricing shown in Table III are equally astonishing. For example, the average size of the mispricing between the TIPS and Treasury bonds maturing in January 2029 and February 2029, respectively, is \$6.84. Similarly, the average basis-point size of the mispricing between the TIPS and Treasury bonds maturing in January 2014 and December 2013, respectively, is 103.66 basis points. We note that the average basis-point size of the mispricing is fairly uniform across all maturities. Thus, there does not

[12] Specifically, the Treasury issued 34 TIPS bonds prior to the end of the sample period. One of these issues had matured by the beginning of the sample period. Four issues had maturity mismatches in excess of 31 days.

[13] Examples of fixed-income arbitrage mispricing reported in the literature include Cornell and Shapiro (1990), Amihud and Mendelson (1991), Boudoukh and White-law (1991), Longstaff (1992, 2004), Daves and Ehrhard (1993), Kamara (1994), Jordan, Jorgensen, and Kuipers (2000), Grinblatt and Longstaff (2000), Longstaff, Santa Clara, and Schwartz (2001), Yu (2006), Duarte, Longstaff, and Yu (2007), and many others.

Table III

Summary Statistics for TIPS-Treasury Mispricing

This table reports summary statistics for TIPS-Treasury mispricing for the 29 pairs of TIPS and Treasury bonds shown. Mismatch in days denotes the maturity mismatch of the pair. The left central panel reports summary statistics for the mispricing measured in dollars per $100 notional. The right central panel reports summary statistics for the mispricing measured in basis points. The sample period is from July 23, 2004, to November 19, 2009.

					Dollar Mispricing					Basis-Point Mispricing					
TIPS		Treasury		Mismatch in Days	Mean	SDev	Min	Max	ρ	Mean	SDev	Min	Max	ρ	N
January 15, 2007	3.375	December 31, 2006	3.000	15	0.18	0.39	−0.76	1.10	0.97	34.57	92.03	−255.56	357.23	0.98	506
January 15, 2008	3.625	December 31, 2007	4.375	15	0.34	0.34	−0.25	1.26	0.96	53.82	66.57	−80.99	270.41	0.96	502
January 15, 2009	3.875	January 15, 2009	3.250	0	0.67	0.46	−0.34	2.56	0.95	72.54	135.34	−25.55	723.29	0.98	1,109
January 15, 2010	4.250	January 15, 2010	3.625	0	0.85	0.59	−1.05	4.69	0.91	55.14	71.91	−64.47	420.39	0.97	1,215
April 15, 2010	0.875	April 15, 2010	4.000	0	1.09	0.65	−1.18	4.51	0.93	58.25	57.84	−69.20	316.69	0.96	1,161
January 15, 2011	3.500	January 15, 2011	4.250	0	1.32	0.71	−0.03	4.94	0.92	50.24	33.67	−1.07	231.07	0.94	971
April 15, 2011	2.375	March 31, 2011	4.750	15	1.67	0.70	−0.37	5.03	0.91	56.13	33.04	−15.24	213.25	0.94	736
January 15, 2012	3.375	January 15, 2012	1.125	0	1.84	0.75	0.79	4.64	0.96	72.32	24.20	31.10	163.04	0.95	215
April 15, 2012	2.000	April 15, 2012	1.375	0	1.42	0.41	0.62	2.32	0.91	54.11	14.90	21.83	90.97	0.90	154
July 15, 2012	3.000	July 15, 2012	1.500	0	1.66	0.37	0.94	2.89	0.86	60.25	12.44	35.72	104.19	0.83	91
April 15, 2013	0.625	March 31, 2013	2.500	15	2.19	1.18	−1.07	6.37	0.95	55.44	28.02	−24.54	156.69	0.95	395
July 15, 2013	1.875	June 30, 2013	3.375	15	4.02	1.83	1.77	9.36	0.98	96.27	39.99	49.04	212.92	0.97	353
January 15, 2014	2.000	December 31, 2013	1.500	15	4.38	1.50	2.30	7.86	0.98	103.66	30.32	59.34	173.67	0.97	225
April 15, 2014	1.250	March 31, 2014	1.750	15	1.76	0.30	1.07	2.58	0.85	41.24	6.97	23.77	56.82	0.85	143
July 15, 2014	2.000	June 30, 2014	2.625	15	3.01	0.48	2.04	4.04	0.95	67.20	9.76	46.45	88.47	0.93	101

(*Continued*)

Table III—*Continued*

TIPS		Treasury		Mismatch in Days	Dollar Mispricing					Basis-Point Mispricing					
					Mean	SDev	Min	Max	ρ	Mean	SDev	Min	Max	ρ	N
January 15, 2015	1.625	February 15, 2015	4.000	31	3.36	2.04	1.22	12.52	0.99	55.48	37.53	15.62	214.11	0.99	1,204
July 15, 2015	1.875	August 15, 2015	4.250	31	3.61	2.18	1.54	13.24	0.99	56.39	36.45	22.68	207.57	0.99	1,079
January 15, 2016	2.000	February15, 2016	4.500	31	4.01	2.29	1.63	13.14	0.99	59.66	35.41	22.46	206.56	0.99	950
July 15, 2016	2.500	June 30, 2016	3.250	15	3.76	0.59	2.46	4.99	0.98	62.34	9.63	40.75	82.58	0.98	101
January 15, 2017	2.375	February 15, 2017	4.625	31	4.27	2.35	1.51	12.56	0.98	58.22	31.97	18.92	166.06	0.98	698
July 15, 2017	2.625	August 15, 2017	4.750	31	4.43	2.34	1.70	11.20	0.97	57.29	29.83	20.51	143.82	0.97	573
January 15, 2018	1.625	February 25, 2018	3.500	31	5.00	2.51	2.13	12.05	0.98	65.33	31.57	26.99	147.04	0.97	446
July 15, 2018	1.375	August 15, 2018	4.000	31	5.38	2.62	1.78	12.31	0.98	65.78	29.84	21.72	137.22	0.97	320
January 15, 2019	2.125	February 15, 2019	2.750	31	5.32	2.08	2.56	10.14	0.99	68.36	24.60	33.66	123.37	0.99	194
July 15, 2019	1.875	August 15, 2019	3.625	31	3.94	0.78	2.40	5.09	0.99	47.98	9.44	29.05	62.51	0.99	68
January 15, 2025	2.375	February 15, 2025	7.625	31	4.27	3.57	−0.89	23.06	0.98	29.40	23.45	−5.51	138.97	0.98	1,342
January 15, 2026	2.000	February 15, 2026	6.000	31	4.90	3.16	−0.06	18.49	0.97	36.85	21.96	−0.50	118.59	0.96	961
January 15, 2027	2.375	February 15, 2027	6.625	31	5.30	3.46	0.54	18.53	0.97	36.42	22.03	3.70	108.12	0.96	709
January 15, 2029	2.500	February 15, 2029	5.250	31	6.84	3.49	1.68	15.22	0.98	48.43	23.69	12.22	103.74	0.98	205

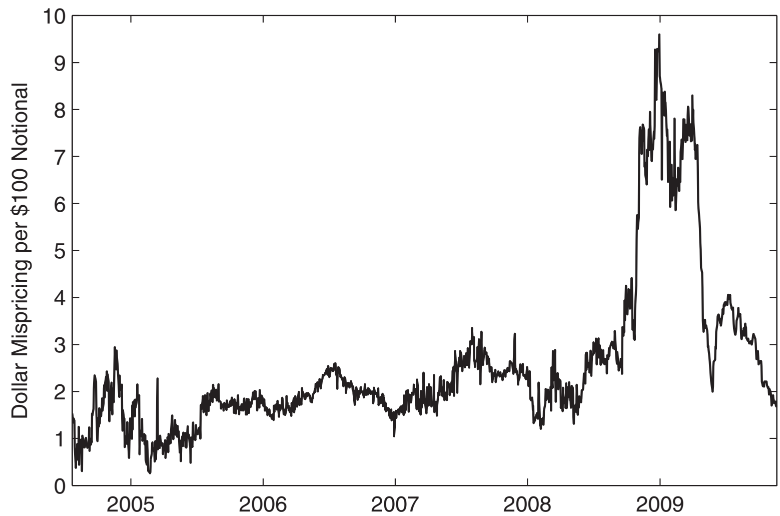

Figure 1. TIPS-Treasury mispricing. This figure plots the time series of the weighted-average TIPS-Treasury mispricing, expressed in units of dollars per $100 notional, across the pairs included in the sample, where the average is weighted by the notional amount of the TIPS issue.

appear to be any relation between the maturity of the TIPS-Treasury bond pair and the average size of the mispricing.

To illustrate the average size of the TIPS-Treasury mispricing, we compute the TIPS notional-weighted mispricing for each date during the sample period, where the average is taken over all TIPS-Treasury pairs in the sample on that date. Figure 1 plots the weighted-average dollar mispricing for the TIPS-Treasury pairs. Figure 2 plots the corresponding weighted-average basis-point mispricing for these pairs. As can be seen, the mispricing is evident throughout the entire sample period, not just during the crisis period from 2008 to 2009. In particular, while the amount of mispricing peaked at $9.60 or 175 basis points around the time of the Lehman bankruptcy in the Fall of 2008, there were clearly earlier periods when the average mispricing was in excess of $3 or about 60 basis points. In addition, Figures 1 and 2 show that there is significant time-series variation in TIPS-Treasury mispricing throughout the sample period. The overall average size of the mispricing is $2.92. The overall average basis-point size of the mispricing is 54.5 basis points.

We note that there are a few cases of negative mispricing. However, these represent only 2.56% of the total observations. We investigated these cases and found that the vast majority were associated with the first four pairs of bonds in Table III. The negative mispricings were fairly evenly distributed throughout the sample period rather than clustered in time. Furthermore, there appeared to be relatively little correlation in the incidence of negative mispricing across bonds; it was rare to have more than one case of negative mispricing at a time. We checked the data carefully to make sure that the negative mispricing was

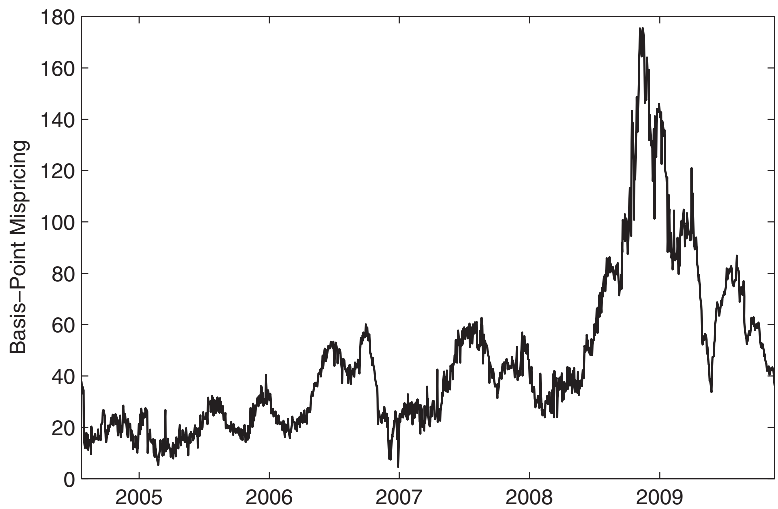

Figure 2. Weighted average TIPS-Treasury mispricing in basis points. This figure plots the time series of the average TIPS-Treasury mispricing, measured in basis points, across the pairs included in the sample, where the average is weighted by the notional amount of the TIPS issue.

not due to errors or outliers. Since the first four pairs of bonds involve TIPS with the highest coupons, the negative mispricings could potentially reflect an investor preference for short-term high-coupon TIPS issues.[14]

It is important to acknowledge that practitioners have long recognized that breakeven inflation spreads appear mispriced relative to inflation swaps.[15] These discussions, however, have generally attributed the discrepancy to some form of risk premium. An important implication of our findings is that the discrepancy cannot be due to a risk premium (defined in the rigorous theoretical sense as a pricing effect arising from the interaction of a security's cash flows with a pricing kernel) since we show that TIPS-Treasury mispricing is a violation of the law of one price and therefore cannot be reconciled with an equilibrium model of asset pricing.[16]

On the other hand, it is not uncommon to see deviations from the law of one price—which we define formally as mispricing—described using alternative terminology such as liquidity effects, liquidity risk premia, arbitrage risk premia, etc. For example, recent papers by D'Amico, Kim, and Wei (2010), Christensen and Gillan (2011a, b, c), and Haubrich, Pennachi, and Ritchken (2012) use the term liquidity risk premia to characterize the component of TIPS prices that cannot be explained within the context of a formal asset

[14] We are grateful to the referee for suggesting this analysis.

[15] For example, see the discussion in United States Governmental Accountability Office (2009) and Pond and Mirani (2011).

[16] Haubrich, Pennachi, and Ritchken (2012) provide an excellent example of an equilibrium model of Treasury and TIPS pricing in which term premia as well as inflation risk premia are explicitly defined.

pricing model. Thus, the difference between what we term mispricing and what these papers call a "liquidity risk premium" is simply a semantic one, and there is no fundamental conflict between their results and ours.[17]

As discussed earlier, the total notional amount of TIPS outstanding has increased significantly over time. In particular, the total amount of TIPS outstanding at the beginning of the sample period in July 2004 was $222.60 billion, but increased to $567.51 billion by the end of the sample period in November 2009. At the end of the sample period, TIPS accounted for 7.91% of the total notional value of marketable U.S. Treasury debt.

From the Treasury's perspective, TIPS-Treasury mispricing represents a potential opportunity for reducing Treasury debt. For example, if Treasury bonds have a higher market valuation than the equivalent inflation-swapped TIPS issues, then the Treasury could potentially generate significant savings by buying back all the outstanding TIPS issues, issuing Treasury bonds with the same maturity, and hedging out the inflation risk in the inflation swap market. The evidence in Han, Longstaff, and Merrill (2007) suggests that the Treasury is able to buy back large quantities of its debt with only minor market impact costs. To evaluate the potential savings from this type of a debt exchange, we multiply the TIPS-Treasury mispricing by the notional amount of TIPS outstanding and total this value over all pairs of bonds available during the sample period (including the four with maturity mismatches in excess of 31 days).

The total savings from the debt exchange follows a pattern similar to that in Figures 1 and 2. The total increases secularly over the sample because of the increase in the issuance of TIPS. Moreover, it spikes toward the end of 2008 in the wake of the global financial crisis and reaches a peak of $56.4 billion on December 30, 2008. By the end of the sample period, the total savings is $11.2 billion.

Another perspective on this issue is given by computing the cost to the Treasury of issuing TIPS rather than Treasury bonds. This is perhaps a more realistic measure of the costs incurred because the Treasury could clearly have simply issued Treasury bonds rather than TIPS. Figure 3 plots the cumulative total cost to the Treasury of the 27 TIPS issuances during the sample period. The total cost of new issuances during the sample period is $9.6 billion.[18] On January 30, 2009, the Treasury issued $14.01 billion of 20-year TIPS at a cost of $12.00 per $100 notional. This issuance alone cost the Treasury $1.68 billion. Clearly, issuing TIPS during periods of increased volatility in the financial markets and flights to nominal Treasury bonds implies that large new TIPS issuance can be very costly from the taxpayers' vantage point.

[17] We are grateful to the referee for pointing out this distinction. We note that there are formal asset pricing models in which liquidity risk premia arise through the interaction between the timing of cash flows and a pricing kernel. As one example, see Longstaff (2009). These types of liquidity risk premia, however, are fundamentally different from those in the papers cited above.

[18] This number does not include the 0.875% TIPS issue with maturity April 15, 2010, issued on October 29, 2004, because there is not a good match with a Treasury bond for the first part of the sample period.

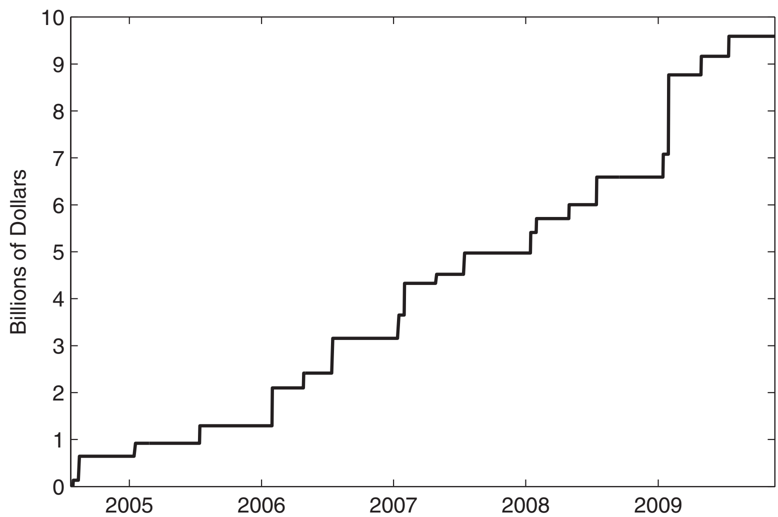

Figure 3. Cumulative total cost to the Treasury from issuing TIPS rather than Treasury bonds. This figure plots the cumulative total cost to the Treasury (measured in billions of dollars) of issuing TIPS rather than Treasury bonds measured across all TIPS auctions during the sample period.

The answer to this question is that it depends on the investor. As shown earlier, the arbitrage strategy is, in fact, an arbitrage in the textbook sense. As is well known, however, even a textbook arbitrage can be a risky venture for an arbitrageur facing constraints. For example, Shleifer and Vishny (1997), Liu and Longstaff (2005), and others show that an arbitrageur subject to margin constraints could suffer mark-to-market losses and be forced to liquidate a position in a textbook arbitrage at a loss prior to the date of convergence. Thus, an arbitrage could essentially be riskless from the perspective of a relatively unconstrained arbitrageur such as a sovereign wealth fund, yet risky from the perspective of a highly leveraged and constrained hedge fund.

Could a hedge fund successfully implement the TIPS-Treasury arbitrage strategy described in this paper? Many hedge funds have already done so. As one example, we quote from recent *Financial Times* blogs by Kaminska (2010) and Jones and Kaminska (2010) about Barnegat Fund Management:[19]

“But as Barnegat explain: ‘We will buy the TIPS, short the nominal bond, and lock in the inflation rate with the inflation swap. The result is that the net initial payment is zero, but until 2014 this trade yields up to 2.5% per year of the notional.’

For a small group of savvy traders, the pricing discrepancies at their widest led to one of the most successful hedge fund trades in recent memory. One of

[19] See Izabella Kaminska, 2010, Who played the largest ever arbitrage? http://ft alphaville.ft.com/blog/tag/barnegat-fund-management and Sam Jones and Izabella Kaminska, 2010, Bond strategy led to big win after Lehman, http://www.ft.com/ intl/cms/s/0/a9832c1e-c109-11df-99c4-00144feab49a, s01=1.html#axzz1TS3yEDOR.

the biggest beneficiaries was the low-profile New Jersey-based $450 million Barnegat fund founded in 1999. Barnegat acquired TIPS bonds shortly after the collapse of Lehman Brothers and then shorted—bet on a fall in rates—regular Treasury bonds of an equivalent maturity. As the pricing discrepancy narrowed, the fund realised huge gains. The fund returned 132.6% to investors in 2009."

We have also had numerous discussions with traders, researchers, and portfolio managers at a variety of hedge funds and investment management firms confirming that similar strategies are widely used in practice.

On the other hand, could *every* hedge fund make money following the TIPS-Treasury arbitrage strategy described in this paper? Probably not. The reason is that some arbitrageurs face constraints that limit their ability to fully realize arbitrage profits from violations of the law of one price.[20] Examples of these types of limits to arbitrage include the costs and funding risks of financing securities positions in the repo markets, as well as the regulatory, mark-to-market, and capital costs of keeping Treasury security positions on the balance sheet. As discussed earlier, our approach in this paper is to focus primarily on the broad implications of TIPS-Treasury mispricing, while abstracting from the narrower issue of the risks that a specific arbitrageur might face in implementing the arbitrage strategy.

As a final note, we observe that there has been a recent increase in market interest in TIPS-Treasury strategies, which are often referred to as breakeven inflation trades. For example, in late 2011, both ProShares Advisors and State Street announced plans to offer ETFs based on long-short positions in TIPS and Treasuries.

II. Inflation Swap Mispricing?

We have shown that a simple no-arbitrage argument imposes a strong restriction on the relative prices of Treasury bonds, TIPS, and inflation swaps, and that this restriction is frequently violated in the market. It is important to observe, however, that, since there are three legs to the arbitrage strategy, mispricing in any one of these three could be responsible for the TIPS-Treasury arbitrage. Because inflation swaps are less familiar to many market participants, it is perhaps natural to suspect that distortions in the pricing of inflation swaps may be the underlying explanation for the results.

In this section, we provide conclusive evidence that the mispricing of inflation swaps cannot explain more than a small portion of TIPS-Treasury mispricing. Specifically, we repeat our analysis by applying the same arbitrage strategy to

[20] One possible example of this might be Morgan Stanley. From a June 29, 2011 Bloomberg article, "The bank's interest-rates trading group lost at least tens of millions of dollars on the trade, which the firm has been unwinding . . . Traders at the bank bet that inflation expectations for the next five years would rise in Treasury markets . . . Such wagers on so-called breakeven rates involve paired purchases and short sales of Treasuries and Treasury Inflation Protected Securities, or TIPS, in both maturities." See http://www.bloomberg.com/news/2011-06-29/morgan-stanley-said-to-suffer-trading-loss-after-wager-on-u-s-inflation.html.

matching corporate fixed-rate and inflation-linked bonds and using the same set of inflation swap prices as before. If inflation swap mispricing were the underlying reason for the TIPS-Treasury results, then we would expect to see the same type of mispricing between corporate fixed-rate and inflation-linked debt since identical inflation swap prices are used in both cases. In actuality, however, we find little or no evidence of systematic mispricing between corporate fixed-rate and inflation-linked debt. Thus, we can definitively rule out that mispricing in the inflation swap market is the source of the TIPS-Treasury mispricing.

A. Corporate Inflation-Linked Debt Arbitrage

During the past decade, a number of corporations have issued inflation-linked debt (linkers). For the most part, these firms have tended to be in the financial sector. Since many of these firms have fixed-rate debt as well, we can directly apply the arbitrage strategy to compare the price of a fixed-rate corporate bond to that of an inflation-swapped corporate inflation-linked bond with cash flows that exactly replicate those of the fixed-rate bond. Note that, in doing so, we use the same inflation swap prices as we used in calculating the TIPS-Treasury mispricing.

Specifically, we search through the Bloomberg system for all corporate inflation-linked debt issues for which we can find a fixed-rate bond for the same firm with a matching maturity date. When there is more than one matching fixed-rate and inflation-linked pair for a firm, we choose the most liquid pair (defined in terms of the number of days on which prices are available). This process results in a sample of fixed-rate and inflation-linked pairs for the following firms: Bank of America, Citigroup, JP Morgan, Morgan Stanley, Prudential, and Sallie Mae. The original maturities of the inflation-linked debt issues are all 10 years. The mismatch in the maturities of the fixed-rate and inflation-linked debt issues ranges from zero days to a maximum of 31 days.

In general, corporate fixed-rate and inflation-linked debt is much less liquid than Treasury debt. This is particularly true during periods in which the underlying firm experiences serious credit issues as is the case for a number of the financial firms in our sample during the Lehman crisis. To address this issue, our approach is to focus on the periods during which the risk of a default for the underlying firm is viewed as small by market participants as reflected by the firm's credit default swap (CDS) spread being below some threshold.

Table IV reports summary statistics for the yield differences between the corporate fixed-rate bonds and the corresponding inflation-swapped portfolio that exactly replicates the cash flows of the fixed-rate bond. For comparison, we also provide summary statistics for the contemporaneous TIPS-Treasury mispricing on the dates when we have an observation for a corporate fixed-rate and inflation-linked pair. The table reports the results using CDS spread thresholds for the underlying firm of 25, 50, 75, and 100 basis points.

As shown, the mispricing between corporate fixed-rate and inflation-linked debt is much smaller than the contemporaneous TIPS-Treasury mispricing

Table IV

Comparison of Corporate Fixed-Rate and Inflation-Linked Debt Mispricing with TIPS-Treasury Mispricing

This table reports summary statistics for the mispricing of maturity-matched pairs of corporate fixed-rate and inflation-linked debt using the same arbitrage strategy as described in Table I and the same set of inflation swap data used to compute TIPS-Treasury mispricing. The sample consists of pairs of fixed-rate and inflation-linked debt for Bank of America, Citigroup, JP Morgan, Morgan Stanley, Prudential, and Sallie Mae. For perspective, the table also reports summary statistics for TIPS-Treasury mispricing for the same dates as the corporate fixed-rate and inflation-linked mispricing observations. Corporate fixed-rate and inflation-linked mispricing observations are computed when simultaneous pricing data for both types of debt are available and when the CDS spread for the underlying firm is less than or equal to the indicated CDS threshold (measured in basis points). Corr. denotes the correlation between the corporate fixed-rate and inflation-linked mispricing observations and the corresponding TIPS-Treasury mispricing observations. The sample period is from July 23, 2004, to November 19, 2009.

	Corporate Mispricing			TIPS-Treasury Mispricing				
CDS Threshold	Mean	Median	Std. Dev.	Mean	Median	Std. Dev.	Corr.	N
25	−6.11	−7.15	56.26	31.78	26.97	13.23	−0.281	465
50	−0.28	−4.34	58.96	31.76	26.88	13.41	−0.164	542
75	7.55	0.68	65.92	32.45	28.06	13.56	−0.052	581
100	9.17	1.09	68.11	32.95	28.35	14.26	0.019	598

for all of the CDS thresholds considered. For example, the average corporate mispricing is only −0.28 basis points when the credit threshold is 50 basis points. In contrast, the average value of the TIPS-Treasury mispricing on the same dates is 31.76 basis points. Note that the median values of the corporate mispricing are all either negative or nearly zero.[21] This provides direct evidence that mispricing in the inflation swap market cannot be the explanation for the TIPS-Treasury mispricing. This follows simply since the same inflation swap prices are used in computing both the corporate and TIPS-Treasury mispricing. Finding that corporate mispricing is nearly zero, on average, shows that the mispricing is unique to the TIPS-Treasury pairs.

As an alternative way of exploring this issue, observe that, if inflation swaps were mispriced, then corporate and TIPS-Treasury mispricing would be highly correlated over time because of their common dependence on the prices of inflation swaps. Table IV, however, shows that there is very little correlation between the corporate and TIPS-Treasury mispricing series. In fact, the correlation between the two time series is negative in sign for three of the four credit thresholds, and nearly zero for the fourth. This provides additional evidence

[21] The standard deviation for the corporate mispricing is several times larger than for the TIPS-Treasury mispricing. The primary reason for this is that the daily TIPS-Treasury mispricing estimates are weighted averages of the mispricing across many TIPS-Treasury pairs. In contrast, the corporate mispricing estimates are based on individual pairs (it is rare to have more than one corporate mispricing estimate per day). Thus, since there is no averaging across different pairs, the daily corporate mispricing estimates appear more volatile.

against the notion that mispricing in the inflation swap market is the source of the TIPS-Treasury mispricing.

As a final diagnostic check, we also use the following approach, suggested by Ashton (2006). For each corporate fixed-rate and inflation-linked pair, we identify a TIPS-Treasury pair with closely matching maturities. Given these two pairs, we can then estimate the credit spread for the fixed-rate corporate bond by subtracting from its yield the yield on the matching Treasury bond. We refer to this as the fixed-rate credit spread. Similarly, we can then estimate the credit spread for the inflation-linked corporate bond by subtracting from its yield the yield on the matching TIPS issue. We refer to this as the inflation-linked credit spread. Intuitively, the two credit spreads should have values that are very similar to each other if the bonds are all fairly priced.

In actuality, however, we find that the fixed-rate credit spread is substantially higher than the inflation-linked spread. The mean difference between the two spreads ranges between 59 basis points to 86 basis points, depending on the CDS threshold. The hypothesis that the difference in spreads is zero is strongly rejected by a simple test of the mean. The implication of these results is that spreads measured relative to Treasury bonds are higher than spreads measured relative to TIPS, consistent with the view that Treasury bonds are rich relative to TIPS.

It is important to recognize that this last comparison does not use any inflation swaps data; this analysis simply compares fixed-rate and inflation-linked yields. Thus, the inference that Treasury bonds are rich relative to TIPS is clearly not an artifact of the pricing of inflation swaps—the same inference holds even when we do not use inflation swaps data in the analysis.[22]

B. Other Potential Factors Affecting Inflation Swaps

The above analysis shows that inflation swap mispricing is not the explanation for the TIPS-Treasury mispricing. It is important to stress, however, that this conclusion does not necessarily imply that inflation swaps are always correctly priced. It simply means that whatever mispricing there may be in the inflation swap market is too small to explain the magnitude of TIPS-Treasury mispricing. For the sake of completeness, however, it is worthwhile to consider the potential impact of other market factors and frictions that have been discussed in the financial press.

B.1. Corporate Inflation-Linked Issuance

A number of market participants have argued that the issuance of inflation-linked debt by corporations creates an artificial inflation-hedging demand among Wall Street dealers. It is also argued that this demand could temporarily distort prices in the inflation swap market.

[22] Our results are also consistent with Ashton (2006), who finds that inflation swaps cannot explain the mispricing between Treasuries and TIPS.

To explore the implications of this hypothesis, we collected weekly data on all U.S. inflation-linked corporate debt issuance during the sample period from the Bloomberg system. We then regress weekly changes in inflation swap rates on weekly inflation-linked debt issuance. We find no evidence that inflation-linked debt issuance affects inflation swap prices.

In addition, we also regress weekly changes in the TIPS-Treasury mispricing on weekly inflation-linked debt issuance. Again, we find no relation between the two time series. Note that TIPS-Treasury mispricing is largest during the financial crisis, and that corporate inflation-linked issuance is almost nonexistent during this period. In summary, these results provide little or no support for the hypothesis that inflation swap pricing or TIPS-Treasury mispricing is driven by corporate inflation-linked debt issuance.[23]

B.2. Counterparty Credit Risk

The financial crisis has focused significant attention on the role of counterparty credit risk in the pricing of derivative contracts. This raises the question of how inflation swap contracts might be affected by the credit risk of inflation swap dealers in the market.[24]

In a recent paper, Arora, Gandhi, and Longstaff (2012) study the effect of counterparty credit risk on the pricing of CDS contracts. They document that differences in the credit risk of dealers selling credit protection have only a very small effect on the pricing of CDS contracts. They argue that the market practice of requiring full collateralization of swap liabilities results in counterparty credit risk having only a tiny effect on the pricing of swap contracts. Their evidence is also consistent with theoretical models of the effect of counterparty credit risk on swap contracts such as Duffie and Huang (1996) and others. Given that there is much less volatility in inflation rates than in credit spreads, the effect of counterparty credit risk on inflation swaps would be even smaller than is the case for CDS contracts. In light of this, it is unlikely that counterparty credit risk has much of an effect on the pricing on inflation swaps.

B.3. Hedging Costs and Illiquidity

Another argument is that inflation swap dealers may face additional costs related to the hedging of their positions that may be impounded into inflation swap prices. Examples of these types of costs might include the cost of financing long and short TIPS and Treasury positions in the Treasury repo markets, the costs of using asset swaps to replicate TIPS and Treasury hedging positions, or the cost of holding collateral. Similarly, it is also argued that, since inflation

[23] We acknowledge, however, that we have not included every possible factor driving inflation swap rates in these univariate regressions. Thus, we cannot fully rule out the possibility of omitted variables bias.

[24] Note that, with bilateral counterparty credit risk, it is not obvious which direction the effect on CDS spreads would be. We are grateful to the referee for this insight.

swaps may be less liquid than Treasuries, inflation swap pricing may reflect this illiquidity.

While it is undoubtably true that swap dealers may face hedging costs, the extent to which this could affect market inflation swap rates is unclear for a number of reasons. For example, dealers in other swap markets such as interest rate swaps and foreign exchange swaps are also exposed to these types of hedging costs. Studies of swap pricing, however, have discovered that these costs have at most a minor effect on equilibrium swap rates.[25] The liquidity of inflation swaps, while less than that of Treasury securities, is still relatively high. As described earlier, industry estimates of the notional size of the inflation swap market are on the order of several hundred billion dollars. Thus, the notional size of the inflation swap market approximates the size of the TIPS market.

III. TIPS and Treasury Bonds

The results above provide strong evidence that TIPS-Treasury mispricing is not due to the pricing of inflation swaps. Thus, TIPS-Treasury mispricing must be driven by the relative valuations of Treasury bonds and TIPS issues. Before exploring the determinants of TIPS-Treasury mispricing, however, is it important to consider whether there are institutional or economic factors that might drive a wedge between the market prices of Treasury bonds and TIPS. In this section, we consider a list of possibilities and briefly evaluate their potential impact. A number of these factors are addressed in the analysis.

A. Tax Differences

The federal and state income taxation of Treasury bonds is identical to that of TIPS in all but one small respect. Specifically, since the notional amount of TIPS accretes over time with realized inflation, taxable investors must treat this "phantom income" as if it were interest income for federal tax purposes. In contrast, taxable investors holding Treasury bonds only include coupons as interest income (abstracting from original issue discount (OID) and premium amortization issues). Interest income from both Treasury bonds and TIPS (including any accreted notional amounts) is exempt from state income taxation.

Although we do not have specific information about the ownership of TIPS, discussions with market participants suggest that a large portion of outstanding TIPS issues are held either directly or indirectly by tax-sheltered entities such as pension plans and retirement funds. Thus, the phantom income provision is irrelevant for many of these investors. This view is consistent with a survey by the Bond Market Association in which 79% of respondents indicated that the current tax status of TIPS is not a deterrent to buying TIPS,

[25] For example, see Duffie and Singleton (1997), Liu, Longstaff, and Mandell (2006), and Johannes and Sundaresan (2007).

some indicating that this was because of the tax-free status of their funds.[26] Finally, it is important to observe that, if the taxation of phantom income were to affect the valuation of TIPS, it should do so uniformly across all issues since the accretion rate is the same for all TIPS. Furthermore, the effects should also be present in the pricing of Treasury STRIPS since they are also subject to the phantom income provisions. In actuality, however, studies of the pricing of Treasury STRIPS have not found evidence of phantom income-related tax effects.[27]

B. Credit Risk

In recent years, it has become clear that the market attaches some positive probability to the event that the U.S. Treasury defaults on its debt. For example, Euro-denominated CDS contracts on the U.S. Treasury traded at spreads as high as 100 basis points during early 2009 (see Ang and Longstaff (2011)). There is an extensive literature on sovereign default risk including Duffie, Pederson, and Singleton (2003), Pan and Singleton (2008), Buraschi, Sener, and Mengütürk (2010), Longstaff et al. (2011), and many others. A key point often made in this literature is that default risk for foreign currency-denominated sovereign debt may differ from that for local currency-denominated debt.

This foreign versus local distinction is relevant for Treasury bonds and TIPS since one can imagine scenarios in which the U.S. might be able to honor its nominal debt by simply "printing more money," but then not be able to pay off its inflation-linked debt. In essence, inflation-linked TIPS can be viewed as equivalent to foreign currency-denominated debt from a sovereign default-risk perspective. If the market views the default risk of Treasury bonds as lower than that of TIPS, then TIPS might trade at prices lower than those implied by the no-arbitrage model.[28]

C. Bid-Ask Spreads

Another possible difference between Treasury bonds and TIPS might be in their trading costs. In reality, however, the costs of trading Treasury bonds and TIPS are both very small. As discussed in Section I.C, the difference in the bid-ask spreads between Treasury bonds and TIPS is probably on the order of three to four ticks, or roughly 15 cents. Together with the earlier results, this implies that TIPS-Treasury mispricing greater than, say, five basis points cannot be explained in terms of transaction costs; the transaction costs are very small relative to the typical size of the pricing differences between Treasury bonds and TIPS.

[26] See http://archives1.sifma.org/research/tips_survey.pdf.

[27] For example, see Grinblatt and Longstaff (2000) and Jordan, Jorgensen, and Kuipers (2000).

[28] CDS contracts on the U.S. Treasury currently do not distinguish between defaults of nominal bonds and TIPS. Industry sources such as ISDA suggest that a default of either type of bond would trigger payment on a U.S. Treasury CDS contract.

D. The Deflation Floor

As discussed earlier, the principal amount of a TIPS issue is protected against deflation since the principal amount received by a TIPS holder at maturity cannot be less than par. Thus, there is an embedded option or deflation floor incorporated into the TIPS issues. Because of this, the value of a TIPS issue may be somewhat higher than it would be if there were no protection against deflation.

The analysis in the previous sections abstracts from the value of the deflation option. It is clear, however, that, if we were to adjust observed TIPS prices by subtracting out the value of the deflation option, then the estimated TIPS-Treasury mispricing would be potentially much larger than reported. Thus, the deflation floor in TIPS prices goes in the wrong direction to explain TIPS-Treasury mispricing.

E. Repo Financing

A difference in an investor's ability to obtain repo financing for TIPS relative to Treasury bonds might induce pricing differences between the two types of Treasury debt. Discussions with bond traders, however, indicate that both types of debt are treated similarly by repo dealers. In particular, both Treasury bonds and TIPS can be financed at government general collateral repo rates with similar levels of haircuts. One trader estimated that the typical haircut applied to Treasury bonds or TIPS issues by large institutional participants in the repo market is on the order of 2% to 3%.

This evidence is consistent with a number of other sources. For example, the Fixed Income Clearing Corporation of the Depository Trust and Clearing Corporation (DTCC) allows dealers to trade general collateral repos through their system and explicitly allows TIPS as a generic security type along with Treasury bonds and STRIPS.[29] The Security Industry and Financial Markets Association (SIFMA) provides repo trading practices guidelines for TIPS.[30] The only difference between their guidelines for Treasury bond repo and TIPS repo is their recommendation that "prices for repurchase agreement transactions involving Treasury Inflation-Indexed Securities be quoted on an 'all-in' price—including the inflation adjustment to the principal amount and the accrued interest on such inflation-adjusted principal." This technical accounting distinction, however, should have no effect on the availability of repo financing for TIPS. Finally, the Federal Reserve Bank of New York explicitly includes TIPS as eligible general collateral for dealer repo transactions with the System Open Market Account.[31] In summary, there is no material difference between Treasury bonds and TIPS in terms of an investor's ability to obtain repo financing.

[29] See http://www.dtcc.com/products/documentation/cs/ficc/gov/GCF_Collateral_Types.pdf.

[30] See SIFMA Restated Repo Trading Practices Guidelines, Update No. 1997-1, TIPS Repurchase Agreement Transactions at http://www.sifma.org/services/standard-forms-and-documentation/government-securities/.

[31] See http://www.newyorkfed.org/aboutthefed/fedpoint/fed04.html.

F. Special Repo Rates

As discussed by Duffie (1996), Fisher (2002), Krishnamurthy (2002), Moulton (2004), Banerjee and Graveline (2013), and many others, holders of on-the-run Treasury bonds may be able to finance their positions at special repo rates that are below general repo rates. This feature confers a potential benefit on the owner of an on-the-run Treasury bond that might be incorporated into the price of the bond and helps explain some of the richness of Treasury bonds relative to TIPS.

Special repo financing, however, cannot fully account for TIPS-Treasury mispricing. First, special repo financing is limited primarily to on-the-run Treasury bonds, while TIPS-Treasury mispricing occurs for virtually all Treasury bond and TIPS pairs. Second, discussions with TIPS traders indicate that on-the-run TIPS issues can also be financed at special repo rates. Finally, the present value of the special repo financing benefit for on-the-run Treasuries is much smaller than the average TIPS-Treasury mispricing for these securities. Specifically, Duffie (1996), Moulton (2004), and Banerjee and Graveline (2013) provide estimates of the differences between overnight/term general and special repo rates ranging from about 30 to 125 basis points. A back-of-the-envelope upper bound calculation shows that, even if a Treasury bond could be financed at a special repo rate 125 basis points below general collateral rates for as long as six months (the maximum time between auctions), the present value of this would only be 62.5 cents per $100 notional. This upper bound is substantially lower than the average size of the TIPS-Treasury mispricing.

G. Collateral Value

Since the principal and interest from both Treasury bonds and TIPS is fully guaranteed by the U.S. Treasury, both types of debt are acceptable collateral for almost all forms of public, private, and banking obligations. To provide some examples, TIPS are equally acceptable as collateral for the Treasury Tax and Loan Program and the Treasury Term Investment Option (see 31 CFR Parts 202 and 203), as collateral for bonds secured by government obligations in lieu of bonds with sureties (see 31 CFR Part 225), and as collateral for uninsured deposits (see 12 CFR 550.320). Similarly, Treasury bonds and TIPS are equally acceptable as collateral for virtually all state and local government purposes. One hedge fund, however, told us that some banks were reluctant to accept TIPS as collateral during the crisis.

H. Eligibility for the Treasury STRIPS Program

Both Treasury bonds and TIPS are eligible for stripping under the Treasury's STRIPS program. The key difference is that stripped coupon from different TIPS issues is not fungible since each issue has its own CPI reference level. The U.S. Treasury's Statement of the Public Debt reports that, on December 31, 2009, 21.22% of the notional amount of all Treasury bonds, 0.49% of the notional amount of all Treasury notes, and 0.03% of the notional amount of all TIPS were held in stripped form. These percentages are fairly stable throughout the sample period.

I. Futures Contracts

Futures contracts on Treasury notes and bonds are traded at the Chicago Board of Trade. Each contract specifies a list of Treasury notes and bonds that are deliverable in settlement of futures positions. In contrast, futures contracts on TIPS are not currently traded on any futures exchange. This distinction likely has little impact on the relative pricing of most Treasury bonds and TIPS. This is because forward purchases or sales of both Treasury bonds and TIPS can be readily executed by institutional participants in the over-the-counter (OTC) market. The key exception might be the case of a cheapest-to-deliver bond at or near the expiration of a futures contract. Market participants, however, indicate that any cheapest-to-deliver effect on Treasury bond prices would typically be very small in magnitude since the Treasury bond/futures basis is actively traded and arbitraged by many financial institutions.

J. Foreign Ownership

We attempt to obtain data on whether Treasury bonds and TIPS differ in terms of the foreign ownership of these securities. Unfortunately, only aggregate foreign ownership data for Treasury bonds and TIPS are available. As of November 2009, the largest foreign holders of U.S. Treasury bonds and TIPS are China and Japan, with holdings of $789.6 billion and $757.3 billion, respectively. We note, however, that an August 2008 report by the Office of Debt Management of the U.S. Treasury Department provides a graph indicating that, during the 2000 to 2008 period, roughly 60% of TIPS were auctioned to dealers and brokers, 30% to investment firms, and 10% to foreign entities. Similarly, Gongloff (2010) reports that foreign demand at TIPS auctions averages about 39%.[32]

K. Institutional Ownership

To explore whether there are differences in the pattern of institutional ownership between Treasury bonds and TIPS, we note that some data on institutional ownership are available via SEC Form 13F filings. In particular, Section 13(f) of the Securities Exchange Act of 1934 requires that institutional investment managers using the U.S. mail (or any other means or instrumentality of interstate commerce) in the course of their business and exercising investment discretion over $100 million or more in Section 13(f) securities must file Form

[32] See Gongloff (2010), TIPS given the cold shoulder, *Wall Street Journal*, April 27, p. C8. Fleming (2007) finds that indirect bidders represent a larger percentage of buyers at TIPS auctions than is the case for Treasury bond auctions.

13F. In making these filings, many of these institutional investors provide information about their holdings of Treasury and TIPS bonds.

Information about institutional holdings of Treasury bonds and TIPS included in these Form 13F filings is compiled by Bloomberg and is summarized for each bond or TIPS issue. We collect data on the TIPS issues in the sample from the Bloomberg system and then collect data for a sample of Treasury bonds with maturities closely matching those of the TIPS issues. We then compare the percentages of the notional amounts held by the institutions filing Form 13F. In doing this, it is important to note that the coverage of Treasury bonds and TIPS issues provided by these Form 13F filings and tabulated by the Bloomberg system may not necessarily be comprehensive.

On average, 31.58% of the notional amount of the TIPS bonds in the sample are reported on Form 13F. The corresponding value for a set of maturity-matched Treasury bonds is 25.02%. Thus, the total percentage amounts reported are similar. A more detailed analysis, however, indicates that there are some intriguing differences in the institutional ownership patterns. In particular, investment firms (mutual funds, investment advisors, etc.) hold 20.69% of the TIPS, but only 4.71% of the matching Treasury bonds. In contrast, the Federal Reserve Bank of New York holds 8.41% of the TIPS, but 17.35% of the matching Treasury bonds. Thus, while the total reported institutional ownership of TIPS and Treasury bonds is similar, the data indicate that investment funds hold a much larger fraction of the TIPS than the Federal Reserve Bank of New York, while the reverse is true for Treasury bonds. Insurance companies hold 2.48% of the TIPS and 2.96% of Treasury bonds. This evidence of partial segmentation in the ownership of Treasury bonds and TIPS is consistent with results in Section VI supporting the slow-moving-capital hypothesis.

L. Bond Dealers and Market Microstructure

We also investigate whether there are differences between Treasury bonds and TIPS in the number and types of institutions functioning as bond dealers. The Federal Reserve Bank of New York maintains a list of primary government securities dealers. This list currently includes BNP Paribas, Bank of America, Barclay's Capital, Cantor Fitzgerald, Citigroup, Credit Suisse, Daiwa, Deutsche Bank, Goldman Sachs, HSBC, Jefferies, J.P. Morgan, Mizuho, Morgan Stanley, Nomura, RBC, RBS, and UBS.

The Federal Reserve Bank of New York also lists the standards expected of primary dealers. For example, primary dealers are expected to meet a $150 million minimum net capital requirement. Furthermore, primary dealers are expected to participate consistently as a counterparty to the New York Fed in its execution of open market operations. Primary dealers are also required to participate in all auctions of U.S. government debt and to make reasonable markets in these securities. These rules make clear that there is no difference between Treasury bonds and TIPS in how these primary dealers are expected to conduct their operations. This is also confirmed by discussions with Treasury bond and TIPS traders who indicate that there is little difference in how bond dealers make markets in the two types of securities. The OTC market microstructure is very similar across the Treasury bond and TIPS markets.

M. Supply Considerations

One clear distinction between Treasury bonds and TIPS issues is in terms of the supply of these securities to the financial markets. To provide some background on the relative size of the TIPS market to the total Treasury bond market, we refer to Table FD-2 of the March 2010 Federal Reserve Bulletin. The ratio of TIPS notional debt outstanding to the total amount of Treasury debt held by the public was 6.67% at the end of 2005, 8.17% at the end of 2006, 9.05% at the end of 2007, 9.02% at the end of 2008, and 7.30% at the end of 2009. Thus, the notional amount of TIPS was less than 10% of the total amount of Treasury debt held by the public during recent years. The ratio increased significantly during the 2005 to 2007 period, but declined during the recent financial crisis as total Treasury debt issuance accelerated.

N. TIPS Liquidity

As one measure of the relative liquidity of TIPS and Treasury bonds, we can examine the average trading volume of the two types of securities by primary dealers. This information is tabulated and reported online by the Federal Reserve Bank of New York as well as SIFMA. Focusing on 2011, the total average daily trading volume of nominal Treasury notes and bonds was \$212.6 billion, which is 2.78% of the total notional amount of these securities outstanding at the end of 2011. The total average daily trading volume of TIPS during 2011 was \$9.5 billion, which is 1.29% of the total amount of TIPS outstanding at the end of 2011. Thus, the trading activity of TIPS is about 46% that of Treasury notes and bonds. These results suggest that, while TIPS are not as actively traded as Treasury notes and bonds, TIPS have a high degree of liquidity. In contrast, using the same metric, the trading activity of all municipal bonds is only 11% that of Treasury notes and bonds during 2011. Similarly, the trading activity of all corporate bonds is only 9.5% that of Treasury notes and bonds during the same period. Similar results hold for the other years in the study period.

We also interview Treasury bond and TIPS traders who confirm this assessment of the relative liquidity of the two markets. In particular, one trader told us that there are roughly 15 dealers who were competitive in providing quotes and would be able to quickly execute purchases and sales of Treasury bonds. In contrast, the same trader indicated that there were only about five dealers who would be able to provide the same level of liquidity for TIPS. Despite this, however, the trader felt that TIPS were liquid and that trades could be executed rapidly.

O. Costs of Shorting Treasury Bonds

To short a Treasury bond, an investor must first borrow the bond through a reverse repo arrangement. In return, the investor allows the owner of the bond to borrow funds at some market-determined rate. Typically, this rate is slightly below the market rate and the difference represents the borrowing cost of the bond. Discussions with traders indicate that it was always possible to short Treasury bonds throughout the sample period.

In extreme situations, however, this spread could widen. For example, during the depths of the financial crisis in the Fall of 2008, an arbitrageur wishing to short a bond might have needed to allow the owner of the bond to borrow at a cost of zero. Since short-term repo rates were on the order of only 25 basis points during this period, however, the effective cost to the arbitrageur of allowing the owner of the bond to borrow at zero was relatively minor.

In mid-2009, SIFMA mandated that repo failures result in the security lender being able to borrow at an annual rate of −300 basis points. This change increased the maximum potential cost to an arbitrageur of short selling Treasury issues in the extreme situation in which the arbitrageur was not able to find a repo dealer willing to lend him the security. Given the timing of this provision, however, it is unlikely to have had much impact on the results reported in this paper.

P. Quantitative Easing

On March 18, 2009, the Federal Open Market Committee (FOMC) of the Federal Reserve announced an unprecedented program to purchase up to $300 billion of longer-dated Treasury bonds through a series of competitive auctions.[33] Over the course of the program, the FOMC purchased $11 billion in nominal Treasury securities maturing in one to two years, $242 billion maturing in two to 10 years, $42 billion maturing in 10 to 30 years, and $5 billion in TIPS. This quantitative easing program (now known as QE 1) affected the tradable supply of Treasury securities in the market, which, in turn, could potentially affect the relative pricing of Treasury bonds and TIPS issues. For a discussion of the QE 1 program, see Krishnamurthy and Vissing-Jorgensen (2010b).

IV. What Drives the Mispricing?

The evidence of significant and persistent mispricing between TIPS and Treasury bonds presents a major puzzle to our understanding of how these markets function. In this section, we explore whether variation in the mispricing is linked to a number of economic and financial variables suggested by the literature or motivated by the discussion in the previous section. By doing this,

[33] Permanent open market operations include purchases or sales of securities on an outright basis that add to or diminish reserves. These are different from temporary open market operations that consist of short-term repurchases or reverse repurchase agreements.

we hope to shed light on the underlying reasons for the mispricing via the identification of factors that may drive the mispricing.

A. The Variables

A number of possible factors might influence the size of TIPS-Treasury mispricing over time. We discuss each of these, in turn, and describe the specific variables used in the regression analysis.

A.1. Supply

The supply of Treasury securities available in the financial markets may be a key factor affecting the ability of arbitrageurs to exploit pricing differences between the TIPS and Treasury bond markets. In particular, it may be easier to execute arbitrage strategies in a market when there is an increase in the supply of on-the-run or recently auctioned bonds. This follows from Kamara (1988, 1994), Cammack (1991), Boudoukh and Whitelaw (1991), Amihud and Mendelson (1991), Krishnamurthy (2002), Han, Longstaff, and Merrill (2007), and others who document that on-the-run bonds differ in terms of their trading and pricing characteristics. To explore the effects of supply on TIPS-Treasury mispricing, we include the total notional amount of all TIPS and all Treasury bonds auctioned each month during the sample period. These data are obtained from the Treasury website.

A.2. Liquidity

An extensive literature documents that liquidity patterns can have significant effects on the valuation of securities. For example, see Boudoukh and Whitelaw (1993), Vayanos and Vila (1999), Acharya and Pedersen (2005), Amihud, Mendelson, and Pedersen (2005), Brunnermeier and Pedersen (2009), Longstaff (2009), Huang and Wang (2010), and many others.

To study the effects of changes in liquidity on TIPS-Treasury mispricing, we include two variables in the analysis. The first is the total notional amount of repo fails experienced by primary bond dealers. Repo fails represent a measure of market disruption caused by investors' inability to find specific Treasury securities in the markets, and directly reflects a breakdown in market liquidity.

Specifically, a repo fail occurs when a primary dealer is not able to deliver a Treasury security that the dealer had previously committed to deliver as part of a securities repurchase agreement. Alternatively, a repo fail occurs when the primary dealer does not receive back a Treasury security pledged as collateral on a repurchase agreement. In either case, the failure indicates that market participants are not able to locate specific Treasury securities. Thus, repo fails should increase during stressed periods in which liquidity and available supply of Treasury securities in the markets dries up. Information on repo fails is reported by the Federal Reserve Bank of New York.

The second liquidity measure is the ratio of total TIPS trading volume by U.S. primary dealers to total coupon-bearing Treasury note and bond trading volume by U.S. primary dealers. Intuitively, changes in this ratio may capture variation in the liquidity of TIPS relative to that of Treasury bonds. Information on trading activity by primary bond dealers is also reported by the Federal Reserve Bank of New York.

We note that we also considered a number of alternative liquidity measures including several suggested by Lesmond, Ogden, and Trzcinka (1999) and Chen, Lesmond, and Wei (2007). In particular, we considered using bid-ask spreads, the percentage of zero returns, and the Lesmond, Ogden, and Trzcinka measure constructed from the frequency of zero returns. Since we do not have reliable time series of bid-ask spreads, we are not able to use bid-ask spreads as a measure of liquidity. Also, given the high level of trading activity in the TIPS market on a daily basis, the observed frequency of zero returns over a month in this market is essentially zero. Thus, measures of liquidity based on the incidence of zero returns do not appear to be applicable in our analysis.

A.3. Credit Risk

As discussed earlier, another possibility might be that the market perceives the credit risk of TIPS as being slightly higher than that of Treasury bonds. In this case, TIPS might appear to be underpriced relative to Treasury bonds. On the other hand, even if the market viewed the credit risk of TIPS and Treasury bonds as equivalent, changes in aggregate credit risk in other markets might influence the relative pricing of TIPS and Treasury bonds. This is because TIPS and Treasury bonds might not be viewed as equally attractive safe havens in the event of a credit-induced flight to quality in the financial markets.

To explore the effects of credit risk on TIPS-Treasury mispricing, we use the 10-year swap spread. Swap spreads are one of the most important indicators of the credit risk of the banking system, and have been widely used as measures of aggregate credit risk.[34] We obtain data on the 10-year swap spread from the Bloomberg system.

A.4. Slow-Moving Capital

A number of recent papers have put forward potential explanations for the existence of persistent mispricing in financial markets. Mitchell, Pedersen, and Pulvino (2007) and Duffie (2010) discuss the role that slow-moving capital may play in allowing arbitrage opportunities to exist for extended periods of time. Shleifer and Vishny (1997), Gromb and Vayanos (2002), Liu and Longstaff (2005), Fostel and Geanakoplos (2008), Gorton and Metrick (2009), and Ashcraft, Gârleanu, and Pederson (2010) argue that margins, haircuts, and other collateral-related frictions may allow arbitrage or deviations from the law of one price to occur. Brunnermeier and Pedersen (2009) emphasize

[34] For example, see Duffie and Singleton (1997) and Liu, Longstaff, and Mandell (2006).

Table V

Results from Regression of Monthly Changes in Average Basis-Point Mispricing on Supply, Liquidity, Credit, and Capital Flow Factors

This table reports summary statistics for the regression of monthly changes in TIPS-Treasury mispricing on the indicated variables. TIPS Issuance denotes the total notional amount of TIPS (in $billions) issued during the month. Treasury Issuance denotes the total notional amount of Treasury notes and bonds (in $billions) issued during the month. Repo Fails denotes the total notional amount (in $billions) of repo failures reported by primary dealers during the month. Trading Ratio denotes the percentage of total monthly TIPS trading volume by primary dealers to total monthly Treasury note and bond trading volume by primary dealers. Swap Spread denotes the monthly basis point change in the 10-year USD swap spread. Hedge Fund Flows denotes the percentage change in total global assets held by hedge funds. The superscript ** denotes significance at the 5% level; the superscript * denotes significance at the 10% level. The sample period is June 2004 to November 2009.

Explanatory Variable	Regression Coefficient	Newey-West t-Statistic
Intercept	3.6174	0.29
TIPS Issuance	−0.5304	−1.85*
Treasury Issuance	−0.0579	−1.71*
Repo Fails	0.0011	2.23**
Trading Ratio	1.9019	0.27
Swap Spread	0.3732	0.99
Hedge Fund Flows	−2.2727	−2.32**
Adj. R^2		0.175
N		66

the role that the availability of funding may play in liquidity effects on security prices.

To explore the implications of the slow-moving-capital literature, we examine whether TIPS-Treasury mispricing is affected by a measure of the amount of capital available in the market that could potentially be directed toward arbitraging mispricing. Specifically, we include changes in total global hedge fund net asset values as estimated by Hedge Fund Research Inc. and reported in the Bloomberg system.

B. Regression Analysis

To explore the relation between the above variables and TIPS-Treasury mispricing, we regress monthly changes in the mispricing on the corresponding changes or values of the explanatory variables. Rather than doing this at the level of individual TIPS and Treasury pairs, however, we focus on the average yield mispricing across all pairs, where the average is weighted by the outstanding notional amount of the TIPS issue (taking into account the accretion in the notional amount). Table V reports the regression results.

The results in Table V provide a number of interesting insights into the determinants of TIPS-Treasury mispricing. First, the results indicate that the mispricing is affected by the supply of new Treasury securities. In particular, the notional amounts of both TIPS and Treasury issuance are statistically significant (at the 10% level). Surprisingly, both regression coefficients are negative in sign. Thus, TIPS-Treasury mispricing decreases in magnitude whenever the Treasury issues TIPS or Treasury bonds. An important implication of this result is that it is not the relative amounts of TIPS and Treasury bonds in the market that affects mispricing. Rather, it is the presence of liquid on-the-run Treasury securities of either type in the market that allows arbitrageurs to drive prices closer together.

This implication is reinforced by the results for the liquidity measures. Specifically, the amount of repo fails is significantly related to TIPS-Treasury mispricing. Thus, when the market experiences liquidity disruptions as primary dealers are unable to receive or deliver Treasury securities that they have purchased or sold, TIPS-Treasury mispricing increases. These results provide clear evidence that the supply or liquidity of the securities involved in the arbitrage is directly linked to the size of the arbitrage. As far as we are aware, this is the first time that such a result has been documented in the literature.

In contrast, the results indicate that systemic credit risk, as measured by the 10-year swap spread, is not significantly related to the TIPS-Treasury mispricing. We repeat this analysis using other measures of credit risk such as the CDX index of CDS spreads for U.S. investment grade firms as well as the sovereign CDS spread on the U.S. Treasury. Neither of these credit risk measures is significantly related to TIPS-Treasury mispricing.[35] We also test whether monthly changes in mispricing are related to the total amount of Treasury debt purchased as part of the QE 1 program by the Federal Reserve, but find that there is no relation.[36]

Finally, the results provide strong direct support for the implications of the slow-moving-capital hypothesis. In particular, changes in the amount of capital managed by hedge funds are significantly related to TIPS-Treasury mispricing. The coefficient estimate indicates that, as the amount of hedge fund capital increases by 1%, TIPS-Treasury mispricing decreases by 2.27 basis points. This result is particularly striking since not all hedge funds would be willing to take significant positions in long-maturity Treasury bonds or TIPS.

V. Correlated Arbitrage

One important implication of the slow-moving-capital explanation of the persistence of mispricing is that arbitrage in different markets could be driven by a common factor. For example, if capital returns slowly to the fixed-income arbitrage hedge fund sector after periods of flat performance, then arbitrages arising in various types of fixed-income markets could display significant commonality. Motivated by this, we explore the extent to which TIPS-Treasury mispricing is correlated with other types of fixed-income arbitrage.

[35] For a discussion of U.S. sovereign CDS, see Ang and Longstaff (2011).

[36] We note, however, that we did not test whether there were pair-specific effects on mispricing based on which bonds were actually purchased by the Federal Reserve.

In this section, we focus on four well-known types of fixed-income arbitrage strategies or forms of mispricing. The first is the CDS-Corporate bond basis strategy discussed by Duffie (2010). In this strategy, the spread for a CDS contract on a firm is compared with the spread on corporate bonds issued by that firm. In theory, the two spreads should be very similar. In reality, there is often a significant difference between the two spreads, which is termed the CDS/corporate-bond basis (Longstaff, Mithal, and Neis (2005)). Duffie argues that this basis may be a result of slow-moving capital. In particular, entering into a CDS contract requires little capital, while purchasing a corporate bond requires the use of significant capital. Thus, if arbitrage capital in the market is relatively scarce, then the CDS/corporate-bond basis may be able to persist. We were given access to a proprietary time series by a major investment management firm of the CDS/corporate-bond basis for the firms included in the CDX index for the period from January 2005 to November 2009. We average the basis across these firms and compute the monthly changes in the average basis. For simplicity, we refer to this arbitrage as the CDS arbitrage.

The second arbitrage strategy is based on the difference between the CDX index and the average CDX spreads for the 125 firms included in the CDX index. Since contracts on the CDX index trade separately, the market price for a contract on the CDX need not always equal the average value of the CDS spreads in the index. This failure of the index to equal the sum of its parts is similar in concept to the difference between the price of an exchange traded fund (ETF) and the value of the ETF's holdings (Tucker and Laipply (2010)). We were also given access to these data for the same time period as for the CDS/corporate-bond basis strategy described above. We refer to this arbitrage as the CDX arbitrage.

It is important to observe that these two arbitrage strategies are different in terms of their use of capital. To implement the CDS/corporate-bond basis strategy requires an investment in the underlying corporate bond and use of the arbitrageur's capital. In contrast, the CDX index arbitrage strategy only requires taking long and short positions in CDS contracts, involving little or no capital. Also, note that neither of these two arbitrage strategies involves Treasury bonds or TIPS. Thus, finding that these strategies and TIPS-Treasury mispricing are correlated would provide evidence in support of the implications of the literature described above.

The third type of mispricing is the yield difference between on-the-run and off-the-run Treasury bonds of similar maturities (see Krishnamurthy (2002)). Specifically, we use the on-the-run/off-the-run Treasury yield curve computed in the Bloomberg system (Curve USD Z111), and take the difference between the on-the-run 10-year yield and the off-the-run nine-year yield.

The fourth type of mispricing is the yield difference between 10-year Refcorp and Treasury STRIPS (see Longstaff (2004)). Since Refcorp bonds are guaranteed by the Treasury, these bonds should have identical yields to those of comparable maturity Treasury bonds. Thus, their difference represents a simple violation of the law of one price. Longstaff shows that the Refcorp-Treasury spread is influenced by a number of market liquidity measures.

Table VI

Results from the Regression of Monthly Changes in Average Basis-Point Mispricing on Monthly Changes in CDS Mispricing, CDX Mispricing, On/Off-the-Run Spreads, and Refcorp/Treasury Spreads

This table reports summary statistics for the regression of monthly changes in TIPS-Treasury mispricing on the indicated contemporaneous and lagged monthly changes in the CDS and CDX arbitrage measures, and on the On/Off-the-Run and Refcorp-Treasury spreads. All mispricings and spreads are measured in basis points. The superscript ** denotes significance at the 5% level; the superscript * denotes significance at the 10% level. The sample period is June 2004 to November 2009.

Explanatory Variable	Regression Coefficient	Newey-West t-Statistic
Intercept	0.1698	0.12
CDS_t	0.0986	1.77*
CDS_{t-1}	0.0599	1.25
CDS_{t-2}	−0.1937	−3.59**
CDX_t	−0.1940	−1.85*
CDX_{t-1}	−0.4390	−3.60**
CDX_{t-2}	0.3335	3.97**
On/Off_t	0.5093	0.84
On/Off_{t-1}	−1.2045	−2.02**
On/Off_{t-2}	1.1413	2.39**
$Refcorp_t$	0.3445	2.11**
$Refcorp_{t-1}$	−0.4088	−3.85**
$Refcorp_{t-2}$	0.2014	1.23
Adj. R^2		0.616
N		66

Table VI reports the results from the regression of the monthly changes in the TIPS-Treasury mispricing index on the current and lagged monthly changes in the CDX and CDX arbitrage measures as well as the on-the-run/off-the-run spread and the Refcorp-Treasury spread. As shown, there is a strong relation between changes in TIPS-Treasury mispricing and changes in the other arbitrage or mispricing measures. In particular, nine of the 12 current or lagged values of these mispricing measures are statistically significant. Overall, changes in these mispricing measures explain a major fraction of the variation in the TIPS-Treasury mispricing; the R^2 for the regression is 0.691 and the adjusted R^2 is 0.616.[37]

These results provide strong support for the hypothesis of correlated arbitrage. The fact that measures of arbitrage in the corporate bond and CDS markets as well as in the Refcorp market are able to explain such a large proportion of TIPS-Treasury mispricing argues that there is some strong commonality in

[37] Note that the signs of the regression coefficients are arbitrary since, for example, an arbitrage could be defined as cash versus synthetic, or, just as easily, synthetic versus cash. For this reason, we focus primarily on the R^2 from the regressions.

observed arbitrage mispricing that transcends markets.[38] Clearly, the notion of slow-moving capital in financial markets is one possible explanation for why there could be correlated arbitrage in multiple markets at the same time.

VI. Predictable Arbitrage

Another important implication of the slow-moving-capital explanation is that mispricing in the market should be predictable on the basis of changes in the amount of capital invested in the financial markets. For example, imagine that investors collectively experience a major increase in their wealth as the stock market rallies. With the increased availability of financial capital, some of this capital would move slowly into mispriced markets and lead to a subsequent decline in the size of the mispricing. Thus, there should be an inverse relation between increases in current wealth and future declines in arbitrage mispricing.

To explore this implication of the slow-moving-capital explanation, we regress ex-post changes in TIPS-Treasury mispricing on three ex-ante measures of changes in the amount of capital available in the markets. The first is simply the excess return on the value-weighted CRSP index (data provided by Ken French). The second is the return on a portfolio of all Treasury bonds (index computed and reported by the Bloomberg system). The third is the return on the value-weighted Hedge Fund Research (HFR) index of all hedge funds. Table VII reports the results from the forecasting regression.

As shown, the lagged stock, bond, and hedge fund returns have very strong forecasting ability for changes in TIPS-Treasury mispricing. The R^2 for the regression is 0.523; the adjusted R^2 is 0.471. Thus, roughly half of the variation in TIPS-Treasury mispricing during a month is predictable on the basis of returns in other markets during the previous two months.

Table VII shows that five of the six lagged returns are statistically significant. The first lagged stock return has a negative sign. Similarly, both the first and second lagged bond market returns are significant and negative in sign. Finally, the second lagged hedge fund index return is significant and negative in sign. These negative relations between changes in TIPS-Treasury mispricing and prior returns are consistent with the slow-moving-capital hypothesis. In particular, the results provide evidence consistent with the intuition that, as investor wealth in the stock, bond, and hedge fund markets increases, more capital is available to arbitrage away mispricing in the TIPS and Treasury markets. Note that these results are consistent with the view that the movement of capital may take place via a gradual reallocation of capital from a variety of asset classes to a mispriced asset class, rather than simply the slow deployment of fixed-income arbitrage hedge fund capital to fixed-income arbitrage opportunities.

[38] There are other examples of fixed-income mispricing measures that might be interesting to explore in future work including the Hu, Pan, and Wang (2011) measure of dispersion of Treasury bond yields around a smooth yield curve.

Table VII

Results from the Forecasting Regression of Monthly Changes in Average Basis-Point Mispricing on Lagged Stock, Bond, and Hedge Fund Returns

This table reports summary statistics for the regression of monthly changes in TIPS-Treasury mispricing on the indicated lagged stock, bond, and hedge fund returns. Stock denotes the excess return on the CRSP value-weighted index. Bond denotes the return on the Bloomberg index of all Treasury debt with maturities in excess of one year. HedgeFund denotes the return on the HFRI value-weighted index of all hedge funds. The superscript ** denotes significance at the 5% level; the superscript * denotes significance at the 10% level. The sample period is June 2004 to November 2009.

Explanatory Variable	Regression Coefficient	Newey-West t-Statistic
Intercept	5.6081	2.61**
Stock_{t-1}	−1.8203	−2.95**
Stock_{t-2}	2.1812	3.33**
Bond_{t-1}	−4.3274	−3.24**
Bond_{t-2}	−3.5386	−2.82**
HedgeFund_{t-1}	0.3471	0.23
HedgeFund_{t-2}	−3.8906	−2.62**
Adj. R^2		0.471
N		66

Another dimension that might be interesting to explore in future work is the notion that mispricing might not only be a function of the supply of arbitrage capital, but also the demand for arbitrage capital. In particular, the demand for arbitrage capital might depend on the number and types of arbitrages available in the financial markets. It is certainly true that there were many other types of fixed-income mispricings in the market around the time frame of our study period besides those we discuss. See, for example, Froot (2001), Krishnamurthy (2010), Buraschi, Sener, and Mengütürk (2010), Stanton and Wallace (2011), and Bai and Collin-Dufresne (2011).[39]

VII. Conclusion

In this paper, we study the relative pricing of TIPS and Treasury bonds. A simple no-arbitrage argument places a strong restriction on the relation between the prices of these securities. We show that this no-arbitrage relation is frequently violated in the markets. The mispricing, which can exceed $20 per $100 notional amount, is among the largest ever documented in the literature. Furthermore, the sheer magnitude of this mispricing in markets as deep and actively traded as the Treasury bond and TIPS markets presents a serious challenge to conventional asset pricing theory.

We use this mispricing as a vehicle to explore the implications of recent theoretical work on the role of slow-moving capital. We find strong support for this

[39] We are grateful to the referee for this insight.

explanation of the persistence of mispricing in financial markets. In particular, we show that TIPS-Treasury mispricing narrows as additional capital flows into the hedge fund sector, that TIPS-Treasury mispricing is correlated with arbitrage mispricing in other markets, and that TIPS-Treasury mispricing can be forecast using measures of changes in aggregate investor wealth.

Finally, we show that TIPS are almost always too "cheap" relative to Treasury bonds. An immediate implication of this is that the Treasury could have reduced the cost of the public debt by issuing only nominal bonds, or, alternatively, by actually buying back TIPS and replacing them with nominal bonds. Thus, while there may be solid reasons for issuing TIPS, our results suggest that the policy may be far more costly than previously recognized. This is because the Treasury not only gives up a fiscal hedging option by issuing TIPS, but also leaves billions of dollars on the table by issuing securities that are not as highly valued by the market as nominal Treasury bonds.

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Appendix

A. *Measuring TIPS-Treasury Mispricing*

This section of the Appendix describes how we compute the size of the TIPS-Treasury mispricing. In addition to the pricing data for TIPS, Treasury bonds, and STRIPS issues, we also download daily closing prices of inflation swaps with maturities of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 20, 25, and 30 years for the period from July 23, 2004, to November 19, 2009, from the Bloomberg terminal. Inflation swaps are identified on the Bloomberg system by the ticker USSWIT*n*, where *n* denotes the maturity of the swap. For a few of these swaps, inflation swap data are missing for several days. In these cases, we replace missing data points by the last available observation.

To implement the arbitrage strategy, we set the notional amount of each inflation swap to match the corresponding semiannual coupon payment (before inflation adjustment) on the TIPS issue, which we designate s. At date t, the inflation swap pays a cash flow of $s(1+f_t)^t - sI_t$, where I_t is the indexed leg and f_t is the fixed inflation swap rate for maturity t.

Implementing the arbitrage strategy requires interpolating the quoted inflation swap rates for all maturities ranging from 0 to 30 years. Furthermore, seasonal patterns in inflation must be taken into account for swap maturities that include fractional years (e.g., 2.3 years). To interpolate the inflation swap rate curve, we first fit a standard cubic spline through the quoted maturities using a grid size of one month. Let the interpolated swap rates be denoted by $f_{i,j},\ i = 1, 2, \ldots, 30,\ j = 1, 2, \ldots, 12$, where the first index refers to the year and the second to the month.

We then estimate seasonal components in inflation from the monthly non-seasonally adjusted U.S. CPI index (CPI-U NSA) series between January 1980 and October 2009 by estimating an OLS regression of monthly log changes in the CPI index on month dummies. More specifically,

$$\Delta CPI_t \equiv \log\left(\frac{CPI_t}{CPI_{t-1}}\right) = \sum_{i=1}^{12} \beta_i \, d_i \; + \; \varepsilon_i, \tag{A1}$$

where t is measured in months. The month dummies d_i, $i = 1, 2, \ldots, 12$, are defined as

$$d_i = \begin{cases} 1, & for\ month\ i, \\ 0, & otherwise, \end{cases}$$

and d_1 =January, d_2 =February, ... , d_{12} =December. We obtain an estimate of the seasonal effect in month i by subtracting the average of the coefficients $\bar{\beta} = \frac{1}{12}\sum \hat{\beta}_i$ from the estimated coefficients $\hat{\beta}_i$, $i = 1, 2, \ldots, 12$. Let this estimate be denoted by $\hat{b}_i = \hat{\beta}_i - \bar{\beta}$, $i = 1, 2, \ldots, 12$.

Next, we construct monthly forward rates $H_{i,j}$, $i = 1, 2, \ldots, 30$, $j = 1, 2, \ldots, 12$, from the interpolated swap rates $f_{i,j}$. We then normalize the seasonal factors $\hat{b}_i$ so that their product is unity. Let the normalized monthly adjustment factors be denoted by $\hat{m}_i$, $i = 1, 2, \ldots, 12$, where $\prod_{i=1}^{12} \hat{m}_i = 1$. We then multiply the forward rates $H_{i,j}$ by the corresponding adjustment factor $\hat{m}_j$, $j = 1, 2, \ldots, 12$, to obtain seasonally adjusted forward rates $\tilde{H}_{i,j}$, $i = 1, 2, \ldots, 30$, $j = 1, 2, \ldots, 12$. By construction, there will be no seasonal effects for full-year swaps. In the last step, we obtain the seasonally adjusted inflation swap curve by converting the forward rates $\tilde{H}_{i,j}$ into inflation swap rates $\tilde{f}_{i,j}$, $i = 1, 2, \ldots, 30$, $j = 1, 2, \ldots, 12$. We do not interpolate or adjust maturities smaller than one year, but use the one-year swap rate instead because the interpolated rates are sensitive to short-term inflation assumptions in that case. We set $\tilde{f}_{0j} = f_1$, $j = 1, 2, \ldots, 12$.

With the inflation swap curve, we can now implement the TIPS-Treasury arbitrage strategy and compute the size of the mispricing as follows. First, we take a position in a TIPS issue with a semiannual coupon rate of s and maturity T for a price of V. Each period, the TIPS issue pays coupons of sI_t and makes a principal payment of $100I_T$ at maturity.

Next, we enter into an inflation swap for each coupon payment date $t = 1, 2, \ldots, T$ with notional amount s for $t < T$ and $s + 100$ for the final principal payment at time T. Let f_t denote the fixed rate on the inflation swap for date $t = 1, 2, \ldots, T$ obtained from the interpolated inflation swap curve. At each coupon payment date t, the inflation swap pays a cash flow of $s(1 + f_t)^t - sI_t$ and $(s + 100)(1 + f_T)^T - (s + 100)I_T$ at maturity T. The sum of the cash flows at date t from the TIPS issue and the inflation swap is constant, since $sI_t + s(1 + f_t)^t - sI_t = s(1 + f_t)^t$. Similarly, at maturity, $(s + 100)I_T + (s + 100)(1 + f_T)^T - (s + 100)I_T = (s + 100)(1 + f_T)^T$. This converts all of the indexed cash flows from the TIPS bond into fixed cash flows.

Let P and c denote the price and the semiannual coupon payment for the Treasury bond, respectively. To match the cash flows c from the Treasury bond exactly, the replicating portfolio must include a small long or short position in

Treasury STRIPS for each coupon payment date t and maturity date T such that $s\,(1+f_t)^t + x_t = c$ and $(s+100)\,(1+f_T)^T + x_T = c + 100$, where x_t denotes the notional amount of STRIPS for date $t = 1, 2, \ldots, T$. This step converts the indexed bond into a synthetic security with fixed cash flows that exactly replicate the magnitude of the cash flows from the Treasury bond. Given the fixed cash flows and the value of the replicating portfolio, we then calculate the yield to maturity for the replicating portfolio.

In the last step, we use the yield to maturity for the replicating portfolio to determine the price of a synthetic Treasury bond with the same maturity, coupon rate, and cash flows as the matched Treasury bond. The difference between the prices of the synthetic Treasury bond and the matched Treasury bond represents the TIPS-Treasury mispricing.

B. Measuring Corporate Fixed-Rate and Inflation-Linked Mispricing

Next, we describe how we implement the arbitrage strategy in the corporate bond market to compute the mispricing between corporate fixed-rate bonds and corporate inflation-indexed bonds (linkers). The strategy is analogous to the TIPS-Treasury arbitrage strategy. We create a synthetic fixed-rate bond from a corporate inflation-linker issue by converting the inflation-indexed coupons to fixed payments using inflation swaps. We obtain daily closing prices for corporate inflation-linked and fixed-rate bonds issued by the same companies from the Bloomberg terminal for the period from July 23, 2004, to November 19, 2009.

Analogous to the TIPS-Treasury analysis, we define maturity mismatch as the number of days between the maturity of a corporate fixed-rate bond issue and that of an inflation-linked bond by the same company. We only include pairs of corporate inflation-linked and fixed-rate bonds in the sample if the maturity mismatch is less than or equal to 31 days. For many inflation-linked issues, there is either no pricing data available or the pricing history consists only of a few observations. Due to this limitation and the 31-day restriction on the maturity mismatch between corporate inflation-linked and fixed-rate bonds, the final data set consists of six pairs from six distinct companies: Bank of America, Citigroup, J.P. Morgan, Morgan Stanley, Prudential, and Sallie Mae. The maturities range from July 15, 2011, for the Prudential issue to December 1, 2017, for the Morgan Stanley issue. The maturity mismatches are between zero days for the Bank of America issue and 31 days for the Sallie Mae pair.

In contrast to TIPS, all inflation-linked corporate bonds in the sample pay monthly coupons linked to the realized year-on-year inflation rate. The reference index is the nonseasonally adjusted U.S. CPI index (CPI-U NSA). Furthermore, the corporate inflation-linked issues are not capital indexed, and only the monthly coupon rate varies with realized year-on-year inflation. For all inflation-indexed bonds in the sample, the coupon rate is bounded below by zero. For example, the coupon rate for the J.P. Morgan index-linked bond with maturity March 15, 2014, is the maximum of the realized year-on-year inflation rate + 145 basis points and zero.

To replicate exactly the semiannual cash flows of the fixed-rate bond, we use inflation swaps to swap out the inflation-indexed payments of the indexed bond. Implementing the arbitrage strategy requires interpolating the quoted inflation swap rates. Analogous to the TIPS-Treasury analysis, we interpolate the inflation swap rate curve by fitting a standard cubic spline through the quoted maturities using a grid size of one month. Let the interpolated swap rates be denoted by $f_{i,j}$, $i = 1, 2, \ldots, 30$, $j = 1, 2, \ldots, 12$, where the first index refers to the year and the second to the month. Analogous to the TIPS-Treasury analysis, we estimate seasonal components in inflation from the monthly non-seasonally adjusted U.S. CPI index (CPI-U NSA) series between January 1980 and October 2009 by estimating an OLS regression of monthly log changes in the CPI index on month dummies. The seasonally adjusted forward rates $\tilde{H}_{i,j}$, $i = 1, 2, \ldots, 30$, $j = 1, 2, \ldots, 12$, are obtained in the same way as in the TIPS-Treasury analysis.

Next, we construct an implied CPI index from the seasonally adjusted forward rates obtained in the last step. Let the implied index level be denoted by $\overline{CPI}_{i,j}$, $i = 1, 2, \ldots, 30$, $j = 1, 2, \ldots, 12$. Lastly, we compute one-year forward rates from the implied index values $\overline{CPI}_{i,j}$. For $\overline{CPI}_{0,j}$, we use the known reference CPI index level at that date as the base index in the calculation of the forward rates. This reflects the fact that we do not interpolate or adjust maturities smaller than one year and use the one-year swap rate instead as in the TIPS-Treasury analysis. Let the one-year forward rates be denoted by $\tilde{f}_{i,j}$. Here, forward, we write $f_{i,j}$ instead of $\tilde{f}_{i,j}$.

We then implement the arbitrage strategy and compute the size of the mispricing for corporate bonds as follows. First, we take a position in a corporate inflation-linked issue with a semiannual coupon rate of s and maturity T for a price of V. Let I_t denote the year-on-year inflation rate realized at time t. Each period the inflation-linked issue pays a coupon of sI_t and makes a terminal payment of $100 + sI_T$ at maturity. Next, we enter into an inflation swap for each coupon payment date $t = 1, 2, \ldots, T$ with notional s. At each coupon payment date t, the inflation swap pays a cash flow of $sf_t - sI_t$ and $sf_T - sI_T$ at maturity T. The sum of the cash flows at date t from the index-linked bond and the inflation swap is constant, since $sf_t - sI_t + sI_t = sf_t$. Similarly, at maturity, $sf_T - sI_T + 100 + sI_T = 100 + sf_T$. This converts all of the indexed cash flows from the indexed bond into fixed cash flows.

Let P and c denote the price and semiannual coupon payment, respectively, for the fixed-rate bond of the same company. To match the cash flows c from the fixed-rate bond exactly, the replicating portfolio must include short positions in Treasury STRIPS for each monthly coupon of the inflation-linked issue when the coupon payment dates of the inflation-linked and fixed-rate bonds do not coincide. Furthermore, to ensure that the cash flows of the synthetic security reflect the same credit risk as those from the fixed-rate bond, we adjust the STRIPS prices using CDS spreads. We collect CDS spreads for all six companies during the period from July 23, 2004, to November 19, 2009, for maturities of 0.5, 1, 2, 3, 4, 5, 6, 7, and 10 years. Intermediate maturities are obtained by linear interpolation. To adjust the STRIPS prices, we first calculate the yields on the STRIPS and then add the CDS spread for the matching maturity. In the last step, we convert the adjusted yields back to obtain CDS-adjusted STRIPS prices. Henceforth, we refer to the adjusted STRIPS simply as STRIPS.

Let the set of dates t at which only the inflation-linked issue pays a coupon be denoted by $\tilde{T}_l$. Similarly, let the set of dates t at which both the inflation-linked and fixed-rate bonds have scheduled coupon payments be denoted by $\tilde{T}_f$. More specifically, for all $t \in \tilde{T}_l$, $(sf_t - sI_t) + sI_t + x_t = sf_t + x_t = 0$, where x_t denotes the notional amount of STRIPS for date $t \in \tilde{T}_l$. Similarly, for all $t \in \tilde{T}_f$, $(sf_t - sI_t) + sI_t + x_t = sf_t + x_t = c$. At maturity $T \in \tilde{T}_f$, $(sf_t - sI_t) + 100 + sI_t + x_t = sf_t + 100 + x_t = 100 + c$. To obtain STRIPS prices for all dates t, we linearly interpolate between the quoted prices obtained from the Bloomberg system.

The last step converts the indexed bond into a synthetic security with fixed cash flows that exactly replicate the magnitude of the cash flows from the fixed-rate bond. Given the fixed cash flows and the value of the replicating portfolio, we then calculate the yield to maturity for the replicating portfolio. The difference in yields between the synthetic and the fixed-rate bond defines the corporate mispricing in yield space. Analogous to the TIPS-Treasury analysis, we use the yield to maturity for the replicating portfolio to determine the price of a synthetic fixed-rate bond with the same maturity, coupon rate, and cash flows as the matched fixed-rate bond. The difference between the prices of the synthetic bond and the matched fixed-rate bond defines the corporate inflation-linked debt mispricing in price space.

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