What Drives the TIPS-Treasury Bond Mispricing?

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Abstract

Inflation-swapped Treasury Inflation-Protected Securities (TIPS) are usually undervalued compared to cash flow-matched Treasury bonds. From 2005 to 2022, TIPS discounts are persistent, averaging approximately 3.18% of the face value, with a peak of 16.10%. We use J.P. Morgan's proprietary asset swap data to elucidate the factors associated with this persistent mispricing and the extent of this association. The results from feature selection techniques and the variable importance-in-projection method reveal that marking-to-market concerns and intermediation frictions are key to understanding the underpricing of TIPS relative to comparable nominal Treasury securities. We conclude that when strategic concerns overwhelm fundamental analysis, asset prices may deviate from fundamental values over a prolonged period.

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1. Introduction

Aside from nominal Treasury securities, the U.S. government furnishes other types of fixed-income instruments, such as Treasury Inflation-Protected Securities (TIPS) and Treasury floating rate notes (FRN). TIPS allow investors to infer inflation expectations because they are designed to protect investors against realized inflation, as the face value and coupon payments are linked to the consumer price index (CPI).[1] Hence, the difference between the nominal Treasury securities yield and TIPS' real yield can be a measure of market-based inflation expectations known as break-even inflation (BEI). Meanwhile, inflation swaps that aim to hedge or speculate on inflation risks are widely traded in over-the-counter (OTC) derivatives markets, thereby offering more direct vehicles for trading or hedging inflation expectations.[2] In practice, inflation swap rates are often substantially higher than BEI (Fleming and Sporn, 2013)—this is dubbed as the TIPS-Treasury bond puzzle (i.e., the underpricing of TIPS relative to Treasury bonds). This mispricing in TIPS compared to cash-flow-matched and inflation-swapped Treasury bonds violates the law of one price (Fleckenstein et al., 2014).

TIPS discounts in the early years of the TIPS program can be attributed to liquidity (risk) premium (Haubrich et al., 2012; d'Amico et al., 2018; Driessen et al., 2017; Andreasen et al., 2021; Christensen and Gillan, 2012).[3] Market illiquidity issues from late 1990s to early 2000s are considered as "growing pains." Similarly, the violation of the no-arbitrage principle in the TIPS market may be due to slow-moving capital (Mitchell et al., 2007; Duffie, 2010; Mitchell and Pulvino, 2012; Fleckenstein et al., 2014). However, since TIPS remain significantly underpriced

[1] The Bureau of Labor Statistics of the U.S. Department of Labor publishes the non-seasonally adjusted U.S. city average of all items for all urban consumers.
[2] In inflation swaps, payers receive fixed swap strike rates in exchange for realized floating inflation rates.
[3] The first TIPS auction was held on January 29, 1997.

compared to their hypothetical nominal counterparts, TIPS discounts may be driven by factors other than liquidity or slow-moving capital.

This study empirically investigates the potential channels associated with the TIPS-Treasury bond puzzle and the extent of the association. We delineate the forces that may affect the persistent and significant underpricing of TIPS issues relative to nominal Treasury instruments. We consider a practical and insightful framework through which we come up with the following potential channels: a) marking-to-market concerns in textbook arbitrage opportunities (Liu and Longstaff, 2004, among others) and b) aggregated institutional distortions in intermediated markets, in accordance with intermediary asset pricing theories (He and Krishnamurthy 2013; Adrian and Shin 2014; He et al., 2017). We consider various candidate metrics that influence price fluctuations in the fixed income market, including Treasury inconvenience yields (He et al., 2022), ex-ante volatility measures (Britten-Jones and Neuberger, 2000; Bakshi and Madan, 2000; Jiang and Tian, 2005; Carr and Wu, 2009), funding liquidity (Brunnermeier and Pedersen, 2009), and repo specialness (Duffie, 1996; Jordan and Jordan, 1997; Krishnamurthy, 2002; Banerjee and Graveline, 2013).

We utilize J.P. Morgan's proprietary asset swap data to quantify the magnitude of TIPS discounts over Treasury bonds from 2005 to 2022 on a daily frequency. We highlight that our approach, which uses asset swaps, is better than Fleckenstein et al.'s (2014) methodology, which utilizes inflation swaps and Separate Trading of Registered Interest and Principal of Securities (STRIPS), as our approach introduces a far simpler and easily tradable way to match TIPS to their hypothetical Treasury bond counterparts. First, we investigate how TIPS discounts respond to each potential explanatory variable. We find that all our empirical proxies are significantly and positively associated with TIPS discounts at the 1% significance level. As the explanatory variables are highly correlated in the data, we use principal component analysis to obtain a low-dimensional and linearly independent representation of the explanatory variables. We extract two principal components that capture the variations in the correlation matrix of the potential drivers and name the two factors "marking-to-market concerns" and "intermediation frictions" following their economic interpretations. To identify the key driving forces of TIPS discounts, we employ two feature selection techniques: the least absolute shrinkage and selection operator (Tibshirani, 1996) and the adaptive elastic net (Zou and Hastie, 2005). As a robustness check, we implement the variable-importance-in-projection (VIP) method (Wold, 1966, 1975, 1994) and further corroborate the findings of the feature selection methods. In addition, we conduct Bai and Perron's (1998, 2003) test for structural breaks and document the time-varying relationship between potential drivers and TIPS discounts for each regime. The empirical evidence collected from J.P. Morgan's proprietary and extensive dataset over the period suggests that TIPS discounts are mainly associated with marking-to-market concerns; although, the impact of intermediation frictions in the fixed income market regarding TIPS discounts is also substantial.

This study shows that when strategic concerns overwhelm fundamental analysis, asset prices may deviate from equilibrium values for a prolonged period. The literature shows that arbitrage opportunities may exist for a prolonged period because of a) fundamental risks that arbitragers face when implementing arbitrage transactions (Shleifer and Vishny 1997), b) various costs and market frictions (Gromb and Vayanos, 2010), c) slow-moving capital (Mitchell et al., 2007; Duffie, 2010; Mitchell and Pulvino, 2012), or d) portfolio constraints that prohibit textbook arbitrage opportunities from being exploited (Liu and Longstaff, 2004).[4] We provide a practical example of arbitrage costs and persistent mispricing in the TIPS market.

The remainder of this paper is organized as follows. Section 2 discusses the pricing of the TIPS and TIPS markets. Section 3 details our framework for quantifying the magnitude of the TIPS-Treasury bond puzzle and introduces potential drivers that may influence the mispricing. Section 4 presents the data and results. Section 5 concludes the study.

2. The Pricing of TIPS

TIPS protect investors against inflation in the long term. In this section, we discuss inflation issues surrounding TIPS and summarize the illiquidity issues in the early stages of the TIPS program. We then revisit the TIPS-Treasury bond puzzle and introduce potential channels that may be associated with the puzzle.

2.1 TIPS and inflation risk premium

Because the principal amount and coupon payments of a TIPS issue reflect realized inflation, TIPS bear no risk of inflation, whereas nominal yields contain expected inflation and inflation risk premium. The advantage of TIPS having no inflation risk premium may lower the issuer's expected borrowing cost, serving as one of the main reasons for the launching of inflation-indexed bonds in the late 1990s.

[4] The literature on portfolio constraints affecting underinvestment in arbitrages includes agents' heterogeneity (Basak and Croitoru, 2000), wealth constraints (Loewenstein and Willard, 2000), and solvency constraints (Hindy, 1995).

The literature on inflation risk premium reveals the presence of compensation for the risk of inflation. Inflation risk premium is stable over time (Adrian and Wu, 2009) and the inflation risk premium amounts to 50–100 (20–140) basis points for the 5-year (10-year) horizon (Campbell and Shiller, 1997; Buraschi and Jiltsov, 2005). While the term structure of real rates is flat, variations in expected inflation and inflation risk premium account for approximately 80% of the time-varying inflation compensation (Ang et al., 2008). Put differently, the prices of nominal Treasury securities are deflated due to the inflation risk premium because nominal yields include compensation for fluctuations in expected inflation by such degrees. In turn, the U.S. Treasury Department should bear the deflated prices that emanate from positive and substantial inflation risk premium. Other things being equal, issuers of nominal Treasury instruments benefit from eliminating inflation risk premium, thereby increasing bond prices and lowering their borrowing costs (Fleming and Krishnan, 2012). This caveat in the nominal Treasury securities market justifies the U.S. Treasury Department's decision to launch the TIPS program.

2.2 Growing pains

The ex-ante costs of inflation linkers are thought to be indistinguishable from those of nominal Treasuries (Dudley et al., 2009). Given that long-run forecasting errors in inflation expectations average to zero, TIPS prices factor in two major forces that work in opposite directions. First, TIPS do not have to compensate for the inflation risk, which positively affects TIPS prices relative to Treasury securities. Second, the lack of liquidity in the early years results in lower TIPS prices and higher borrowing costs relative to nominal issuance. Eliminating inflation risk would countervail TIPS illiquidity premium during the program's early stages.

Ex-post analysis reveals that the illiquidity premium far outweighs the inflation risk premium; thus, TIPS are priced at relative discounts because of the lack of liquidity. The liquidity premium is estimated at approximately 30 basis points during normal times (Pflueger and Viceira, 2011). The gap between TIPS real yields and risk-free real yields in the early years is 100 basis points (d'Amico et al., 2018). TIPS-bearing liquidity premium are undervalued prior to 2004 and the illiquidity concern has led to TIPS being significantly discounted during the 2008 crisis (Haubrich et al., 2012). Consequently, TIPS in the early years are not cost-effective for issuers (Sack and Elsasser, 2004).

However, Figure 1a shows that market liquidity of TIPS has dramatically improved. For instance, the daily trading volume of TIPS has more than doubled since the early stages of the program or the 2008 global financial crisis. The average daily trading volume of TIPS by primary dealers is $19.42 billion in 2020, $21.60 billion in 2021, and $18.59 billion in 2022, which is 1.23%, 1.25%, 0.97% of the total TIPS outstanding at the end of each year, respectively.[5] Meanwhile, Figure 1b indicates that TIPS outstanding at the end of 2022 accounts for 7.97% of the total marketable securities issued by the U.S. government. Moreover, a strand of the literature reveals that illiquidity issues in the TIPS market have become immaterial. For example, liquidity premium and inflation risk premium are balanced after 2004 (Dudley et al., 2009) and liquidity premium is decreasing and (d'Amico et al., 2018). Moreover, Driessen et al. (2017) reveal that liquidity correction only partially justifies TIPS underpricing, as 29.40% (assuming market segmentation) or 62.06% (assuming market integration) of TIPS discounts remain unexplained.

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[5] According to Securities Industry and Financial Markets Association (SIFMA), the average daily trading volume of Treasury coupon securities (i.e., Treasury notes and bonds) is $409.75 billion in 2020, $446.77 billion in 2021, and $438.14 billion in 2022, which is 2.94%, 2.71%, 2.47% of total outstanding at the end of 2020, 2021, and 2022, respectively. For Treasury bills, the average is $170.85 billion in 2020, $152.85 billion in 2021, and $155.07 billion in 2022, which is 3.44%, 4.05%, and 4.19% at the end of 2020, 2021, and 2022, respectively.

[Insert Figure 1 Here]

2.3 The TIPS-Treasury bond puzzle

Inflation swaps are a tradable form of BEI that exchanges realized inflation against a strike inflation rate.[6] In practice, inflation swap strikes are generally higher than the BEI measures implied from nominal Treasuries and TIPS (Fleming and Sporn, 2013). By taking on such deviations between BEI and inflation swaps and utilizing inflation swaps to translate realized inflation in TIPS to expected inflation, nominal Treasury bonds are synthetically replicated by linearly combining TIPS, inflation swaps, and securitized zero coupon Treasuries (Fleckenstein et al., 2014). The replication strategy further confirms that synthetic Treasury bond prices are significantly lower than nominal Treasury bond prices. Taken together, TIPS discounts violate the law of one price.

Moreover, Fleckenstein et al. (2014) state that other factors, such as taxation differences, inflation swap liquidity, repo financing, value of deflation floor embedded in TIPS, and convexity adjustment between nominal and real yield, are unlikely to affect the mispricing.[7] Rather, they argue that TIPS discounts can be attributed to the fact that a violation of the no-arbitrage condition may not immediately disappear, possibly because capital does not flow

[6] With the presence of inflation swaps, it is argued that the combined liquidity premium in inflation swaps and TIPS results in TIPS discounts (Christensen and Gillan, 2012). Alternatively, Haubrich et al. (2012) conclude that the introduction of inflation swaps in 2003 eliminated TIPS mispricing from 2004 to mid-2008.

[7] Deflation floor represents that TIPS' redemption price at maturity is the higher of face value or the inflation-adjusted notional amount. In case of deflation, this provision protects investors' redemption at face value of TIPS. This safeguard against deflation is only applicable to the principal repayment at maturity. Even though the deflation floor would only be triggered for extreme cases (i.e., deep out-of-the-money option), such as the Great Recession in the 1930s, the deflator clearly has a non-zero positive value. Excluding the deflator at maturity marginally decreases the TIPS prices, and thus widens the price gaps between TIPS and Treasury bonds. Our results rest on TIPS with embedded deflator.

instantaneously (Mitchell et al., 2007; Duffie ,2010; Mitchell and Pulvino, 2012). Nonetheless, Figure 2 displays that inflation swaps are still considerably higher than BEI measures, indicating that price gaps do not disappear but rather exist over a prolonged horizon. Hence, understanding the factors associated with the expansion and contraction of the basis over two decades is essential.

[Insert Figure 2 Here]

2.4 Potential determinants of the TIPS-Treasury bond puzzle

Campbell et al. (2009a) document a connection between institutional influences and TIPS prices, because various types of institutional idiosyncrasies are plausibly associated with inflation-indexed bond yields. The slow development of indirect investment vehicles investing in TIPS, such as mutual funds, may have contributed to high TIPS yields in the early stages, showing a link to the lack of liquidity and slow adjustment to a new type of financial instrument. The low yield in the U.K. inflation linkers market is probably due to strong demand by U.K. pension funds, representing the demand and supply effects in inflation-indexed bond markets (Greenwood and Vayanos, 2014). A liquidity episode caused by the collapse of Lehman Brothers resulted in anomalies in the TIPS market and extreme volatility in TIPS yields, as the unwinding of institutional positions created severe circumstances. Collectively, these factors fall within the scope of institutional idiosyncrasies.

Treasury securities are primarily traded in OTC markets, in which intermediaries play a significant role (Allen, 2001). We conjecture that the unique characteristics of intermediated markets are potential sources of TIPS discounts. This direction is consistent with intermediary asset pricing theories, where intermediaries' risk-bearing capacity matters (He and Krishnamurthy, 2013; He et al., 2017; Adrian and Shin, 2014). Specifically, the covariance risk between Treasury securities and equity has altered its signs over time (Campbell et al., 2009b) and intermediation frictions help explain the time-varying beta that represents inconvenience yield of Treasury securities (He et al., 2022). While repo financing is critical in intermediation activities, on-the-run securities confer a special financing benefit to holders in the form of repo specialness (Duffie, 1996; Jordan and Jordan, 1997; Krishnamurthy, 2002; Banerjee and Graveline, 2013). Moreover, intermediaries' capital and margin requirements are associated with market liquidity (Brunnermeier and Pedersen, 2009), affecting asset prices in the financial market (Acharya and Pedersen, 2005).

We also consider strategic concerns, such as concerns about marking-to-market losses. Arbitrageurs may avoid volatile positions if the time-horizon is long. When TIPS discounts are implemented as arbitrage, total profit from the arbitrage is quantified at the initiation of trade. However, as the deal elapses until the matched maturity of TIPS and nominal bonds, unrealized profits and losses in the middle of the suggested investment horizon may significantly differ from the estimated total profits. For instance, if arbitrage opportunities occur with 10-year TIPS, it takes 10 years to fully realize the free lunch, with the possibility of experiencing marking-to-market losses at any time during the same period. Hence, future uncertainty amplifies fluctuations in marking-to-market profits and losses, even in textbook arbitrage deals, which, in turn, makes arbitrage risky for constrained investors (Liu and Longstaff, 2004).[8] We use two ex-ante fixed income uncertainty measures to represent constrained investors' strategic concerns

[8] Ex-ante uncertainties also have a link to liquidity. Overall uncertainty has a significant market-wide impact on individual asset' liquidity and dominate the combined effects of other influential determinants (Chung and Chuwonganant, 2014).

regarding fluctuations in fixed income and relevant derivatives markets. The Merrill Lynch Option Volatility Estimate (MOVE) refers to the implied volatility from options on Treasury securities. The CBOE Interest Rate Volatility Index (SRVIX) by the Chicago Board Options Exchange (CBOE) represents swap market volatility, which is the fair strike of a variance swap contract implied from swaption prices (Britten-Jones and Neuberger, 2000; Bakshi and Madan, 2000; Jiang and Tian, 2005; Carr and Wu, 2009). Table 1 summarizes our proxies for the explanatory variables, as well as their construction and sources.

[Insert Table 1 Here]

3. Quantifying the TIPS-Treasury Bond Mispricing

We reiterate that synthetic Treasury bonds can be replicated via a linear combination of TIPS, inflation swaps, and STRIPS (Fleckenstein et al., 2014). However, this approach requires a basket of inflation swaps and STRIPS maturing at every coupon payment date and maturity date. We can achieve the same results through an asset swap contract without relying on plenty of micro positions in inflation swaps and STRIPS. We believe that utilizing asset swaps rather than numerous inflation swaps and STRIPS is methodologically better, as this new approach is simpler and more practical.

3.1 Replicating a synthetic bond

We recap Fleckenstein et al.'s (2014) methodology and describe how our asset-swap approach can improve and simplify the process. To gauge mispricing in the TIPS market, Fleckenstein et al. (2014) replicate a synthetic bond whose payoffs are identical to those of a nominal Treasury bond. As TIPS payments reflect realized inflation measured by the CPI, two pivotal points are considered for a proper comparison between TIPS and the corresponding Treasury bonds. First, realized inflation in TIPS must be substituted with an expected inflation measure. The inception of inflation-linked derivatives in the early 2000s is critical because inflation swaps make it possible to exchange realized inflation in TIPS payoffs with expected inflation, or vice versa. Second, inflation-swapped TIPS coupons and principal payments must be matched precisely with the corresponding nominal Treasury bond coupons and principal using STRIPS. Consequently, inflation-swapped and STRIPS-matched coupons and principal payment of TIPS reproduce nominal Treasury securities.[9]

[Insert Table 2 Here]

Table 2 summarizes the strategy for creating a synthetic Treasury bond consisting of TIPS, inflation swaps, and STRIPS. Given that the suggested relationship is a linear combination of available assets, the aggregate position of synthetic TIPS must be indistinguishable from corresponding nominal Treasuries in a competitive equilibrium. However, nominal Treasuries are usually more expensive than synthetic Treasuries (Fleckenstein et al. 2014). Thus, a replicating strategy in which traders take a long synthetic TIPS position against shorting a nominal Treasury indicates a textbook arbitrage opportunity. The TIPS-Treasury bond replication strategy shows that the wedge between two U.S. government securities may not be

[9] Andreasen et al. (2021) argue that relying on inflation swaps is debatable due to poor liquidity in inflation swaps. However, a dealer survey in April 2012 shows that indicative bid-ask spreads of inflation swaps are shown to be 2 and 3 basis points, realized bid-ask spreads are reported to be 2.8 basis points, and the overall market size is thought to be around $350 million per day (Fleming and Sporn, 2013). Fleckenstein et al.'s (2014) results are also not associated with distortions in the inflation swap market, such as illiquidity, hedging costs, and counterparty credit risk.

characterized by a traditional rational pricing paradigm. This mispricing clearly violates the law of one price.

Despite its intuitive appeal, Fleckenstein et al.'s (2014) replication strategy has a drawback, as the approach requires a basket of micro positions on inflation swaps and STRIPS to match coupons and notional precisely. For instance, investors who try to replicate a 10-year Treasury bond must trade 20 contracts of inflation swaps and 20 lots of STRIPS whose maturities are in line with the semi-annual coupon payment schedule of the target bond. Trading such micro positions might be onerous and costly because the size of inflation swaps differs from the regular trading size per contract.

3.2 Asset swaps and synthetic floaters

Different from Fleckenstein et al. (2014), we propose a much simpler method of using asset swaps in OTC markets.[10] Rather than establishing a synthetic Treasury bond, we transform TIPS and nominal Treasuries into two identical floaters via asset swaps. Recall that asset swaps are OTC credit derivative contracts that create synthetic FRN. Asset swap buyers purchase spot bonds and enter tailored payer interest rate swaps (IRS). In asset swaps, all cash flows from reference bonds pass through to the IRS counterparties as fixed payers in exchange for the London Interbank Offered Rate (LIBOR) plus asset swap spreads. As such, asset swaps can be considered customized IRS, where the fixed leg pays through coupons and the principal from particular reference bonds, and the floating leg receives LIBOR plus spreads. Importantly, in the case of default, asset swap buyers still need to pay the designated cash flows from the reference

[10] In practice, banks widely utilize asset swaps to manage their balance sheet. Asset swaps convert banks' long-term fixed-rate assets to short-term assets. Consequently, asset swaps enable banks to match asset duration with short-term liabilities, such as deposits.

bond to swap sellers, even though buyers no longer receive the cash flows from the bond. Given that asset swap buyers take on the default risk, the asset swap spreads are considered their compensation for the default-contingent exposure. Specifically, asset swap spreads measure the embedded credit risk of a bond as spreads over the LIBOR.[11]

For TIPS, asset swaps include the exchange of proceeds that comprise both the price of a bond and any accrued interest (i.e., dirty price), future coupon payments from an adjusted principal, and the final redemption. Because an asset swap contract transforms the entire cash flow of a bond into a floater, asset swap spreads represent a bond issuer's credit risk. Hence, an asset swap for TIPS is equivalent to a synthetic FRN issued by the U.S. government. Similarly, the asset swap of a nominal Treasury is identical to that of a synthetic FRN from the same issuer. All other things being equal, an asset swap spread of a TIPS issue and another asset swap spread from a nominal Treasury are identical because both spreads gauge the credit quality of the same issuer. In addition, from the perspective of credit risk, TIPS and nominal Treasuries are subject to the same provisions in the relevant credit markets. Thus, the difference between the two asset swap spreads measures the magnitude of relative mispricing in a simpler way. To summarize, asset swaps transform the price gaps between TIPS and nominal treasuries from a pure credit play to a comparable angle.

Obviously, U.S. government securities are also subject to default with positive credit default swap (CDS) spreads in the credit market. Because TIPS pay coupons and the principal based on inflation-adjusted face values, cash flows from TIPS are concentrated on future dates relative to nominal Treasury securities. Given that the probability of default is non-zero, investors may

[11] For this reason, asset swaps are widely recognized as credit derivatives because asset swap spreads quantify the reference bond' credit risk.

consider nominal Treasury instruments safer than inflation-indexed securities whose effective durations are longer. Asset swaps effectively mitigate these concerns as cash flows are passed through to swap counterparties, eventually leaving typical floaters' cash flows with spreads over the LIBOR. Table 3 illustrates the mechanics of asset swaps that create synthetic floaters from both nominal Treasuries and TIPS.

[Insert Table 3 Here]

Figure 3 displays asset swap spreads of 10-year nominal Treasuries and TIPS. It shows that asset swap spreads of TIPS are usually higher than those of nominal Treasury bonds, indicating the relative underpricing of TIPS to nominal securities from a different perspective. From 2005 to 2022, the gap between the two spreads is 31.80 basis points on average, peaking at 161.01 basis points during the 2008 crisis. The economic magnitude of TIPS discounts is approximately 3.18% (31.80 basis points per annum spreads times 10-year swap tenor) of asset swap notional on average while approaching 16.10% % (161.01 basis points per annum spreads times 10-year swap tenor) of swap notional.[12] Figure 3 further highlights the persistence of the price gaps, which calls for scholarly investigation.

[Insert Figure 3 Here]

4. Data and Results

[12] Fleckenstein et al. (2014) report that TIPS discounts exceed $20 per $100 notional in extreme cases.

Empirical evidence that mispricing (amounting to 3.18% from 2005 to 2022) still exists in the financial market challenges our understanding of how the TIPS market works. In this section, we investigate the factors associated with variations in TIPS discounts in the data. We intend to demystify the factors that may drive the persistent TIPS-Treasury bond mispricing.

4.1 Data and descriptive statistics

We use J.P. Morgan's proprietary dataset to quantify the TIPS discount.[13] We obtain daily data from January. 3, 2005, to December. 30, 2022, but disregard the observations before the 2008 financial crisis. We aggregate the daily data from 2010 to 2022 by week and compute weekly averages to minimize market microstructural noise and house-specific idiosyncrasies. Additionally, we winsorize the variables at the 1% and 99% levels to mitigate the impact of outliers on the results.

Table 4 presents summary statistics for our key variables, while Table 5 presents a correlation matrix between the key variables and TIPS discount. The results show that the key variables are significantly associated with TIPS discounts, and that the key variables are highly intertwined. This complex covariance structure would be addressed in the remaining statistical analyses.

[Insert Tables 4 and 5 Here]

4.2 Univariate regressions

[13] We analyze 10-year TIPS. A 10-year TIPS is the only security introduced in the first auction in January 1997 and continues to be auctioned without discontinuation and reintroduction. The other tenors, such as 5-, 20-, or 30-year, are introduced later, discontinued (and oftentimes reintroduced), or reduced to infrequent issuance schedule. For example, 5-year tenor is first introduced in June 1997, discontinued in 1998, and reintroduced in October 2004. A detailed timeline is available at https://www.treasurydirect.gov/research-center/timeline/tips/.

We first employ simple ordinary least squares (OLS) univariate regressions to confirm the link from each potential driver to TIPS discounts.

$$Y_t = \boldsymbol{X}_t \beta_1 + \boldsymbol{C}_t \gamma_1 + \varepsilon_t \quad (1)$$

where the time interval is daily; $\boldsymbol{Y}$ is a column vector that denotes TIPS discounts or premium in comparison to Treasury bonds; $\boldsymbol{X}$ represents each potential driver of TIPS discounts; $\boldsymbol{C}$ is a control variable matrix; and $\boldsymbol{\varepsilon}$ is a white noise vector. The control variables include the return on the S&P 500 index, the CBOE Volatility Index (VIX), and Moody's seasoned Baa corporate bond yield relative to the yield on the 10-year Treasury constant maturity.[14]

[Insert Table 6 Here]

Table 6 reports the univariate regression results for the TIPS discounts in Eq. (1). All key variables are significantly associated with TIPS deviations at the 1% level, and the F statistics indicate that the regression results are significant. Controlling for the return on the S&P 500 index, VIX, and Moody's seasoned Baa corporate bond yield relative to yield on 10-year Treasury constant maturity, the association between each key variable and TIPS deviations is positive.

The univariate regression in Eq.(1) determines whether each potential driver is associated with TIPS discounts on the margin after control variables are considered. In addition to modeling the marginal effect of each potential driver through observations, we conduct a more stringent test. We consider year-month fixed effects and further test whether the association still exists

[14] The control variables data can be downloaded on the Federal Reserve Economic Data website.

within the on-the-run 10-year TIPS. Table 7 shows the univariate fixed-effects regression results, which confirm that all potential drivers are positively associated with TIPS discounts at the 1% level.

[Insert Table 7 Here]

4.3 Principal components analysis

Table 5 shows that the potential drivers of the TIPS-Treasury bond puzzle are highly correlated. Therefore, we must address multicollinearity issues before running multivariable regressions by utilizing both principal component analysis and feature selection techniques.

First, we check whether a low-dimensional (and linearly independent) representation of the key variable space exists and see whether this new representation can capture as much information as possible. Using Treasury inconvenience yield (direct holdings), Treasury inconvenience yield (indirect holdings), MOVE, SRVIX, TED, and repo specialness, we extract the principal components of the correlation matrix. Moreover, we use one as the threshold of eigenvalues. Table 8 shows that the first two principal components satisfy this threshold value criterion and collectively capture 69.79% of the total variation.

[Insert Table 8 Here]

Table 9 further shows how much and in which direction each potential driver loads on the two principal components reported in Table 8. To interpret each factor, we apply a varimax rotation of the two factors. Values in Table 8 are rounded off to the nearest integer after being multiplied by 100. We place an asterisk on those values greater than 0.50.

[Insert Table 9 Here]

The varimax-rotated factor patterns in Table 9 reveal that Factor 1 is heavily loaded on MOVE and SRIVX; thus, it may denote marking-to-market concerns or liquidity risk for TIPS (Andreasen et al., 2021). Factor 2 is heavily loaded on Treasury inconvenience yields (direct holdings), Treasury inconvenience yield (indirect holdings), TED, and repo specialness; thus, it can capture intermediation costs in the TIPS market. We term the first and second principal components as "marking-to-market concerns" and "intermediation frictions," respectively, and use the two linearly independent principal components in the multivariate regressions instead of the six variables in Table 2. To investigate the impact of each of the two potential channels on TIPS discounts, we first standardize the key variables and linearly combine them into marking-to-market concerns and intermediation frictions. The low-dimensional proxies that denote marking-to-market concerns and intermediation frictions are normalized using their sample averages and standard deviations, allowing for the direct comparison of the magnitude of the estimated coefficients.

4.4 Multivariate results

We use two low-dimensional representations (i.e., marking-to-market concerns and intermediation frictions) of potential explanatory variables and check which channel is empirically correlated with TIPS discounts. Table 10 reports the results. We confirm that both marking-to-market concerns and intermediation frictions are significantly and positively associated with TIPS discounts at the 1% level. Because the two variables of interest are standardized, we conduct a meta-analysis to gauge the relative importance of the variables. Following Ahn (2022) and De Caigny et al. (2020), we compare the absolute values of the test statistics and the magnitude of the estimated coefficients for each variable of interest. In the multivariable regression, the coefficient estimates (test statistics) for marking-to-market concerns and intermediation frictions are 1.5545 and 1.1057 (15.78 and 12.28), respectively. We further test whether one special channel is subsumed in multivariate regressions with year-month fixed effects. Table 11 shows that the impact of intermediation friction is subsumed by marking-to-market concerns in a multivariate setting. Hence, we posit that marking-to-market concerns are likely the key channel for inducing TIPS discounts; although, the impact of intermediation friction remains substantial.

[Insert Tables 10 and 11 Here]

4.5 Selecting key features

Using recent developments in machine learning, we conduct a more formal test to explain the factors associated with TIPS discounts and the extent of the association. Rapach et al. (2013) utilize feature selection techniques to quantify the relative predictability of U.S. returns in the global financial market. Chinco et al. (2019) utilize variable selection techniques to identify key predictors when signals are sparse in the stock market. Following Rapach et al. (2013) and Chinco et al. (2019), we employ least absolute shrinkage and selection operator (LASSO) (Tibshirani, 1996) and adaptive elastic net (Zhou and Hastie, 2005; Zhou and Zhang, 2009; Ghosh, 2011) to disentangle the relative explanatory power of marking-to-market concerns and intermediation frictions.[15]

LASSO performs variable selection and regularization using an ℓ_1 penalty term. The LASSO coefficients minimize the sum of the squared residuals subject to the ℓ_1 penalty term as follows:

$$\Sigma_{i=1}^{n} [y_i - \beta_0 - \Sigma_{j=1}^{p} \beta_j x_{ij}]^2 + \lambda \Sigma_{j=1}^{p} |\beta_j| . \quad (2)$$

When λ is large enough, the ℓ_1 penalty term forces less important or negligible coefficients to degenerate during the optimization process. Thus, LASSO is a key feature-selection technique. LASSO works well when the number of variables exceeds the number of observations; although, in this case, the LASSO criteria are not strictly convex, implying that a unique solution is not guaranteed (e.g., Tibshirani, 2013). This issue is known as "the LASSO problem" in the statistical learning literature. But, if a limited number of key predictors exist at any given point in time, LASSO can be used to determine the data's key features In addition, Chinco et al. (2019, p. 451) note that "if there are only a handful of important predictors at any one point in time, then we can use the LASSO … in a way that would not be possible using an unpenalized OLS regression."

We also consider the adaptive elastic net, as LASSO is known to provide unstable solutions in the case of collinear features (or in situations where one has more features than observations). When two or more features contain identical information, LASSO's objective function fails to find a unique solution. This is because LASSO does not consider the correlation structure of the

[15] Both LASSO and the elastic net turn out to be more robust than other feature selection techniques, for example back or forward stepwise regression. See Bai and Ng (2008) for further details.

explanatory variable set. If the explanatory variables are highly intertwined in the data, LASSO selects only one variable. The elastic net method is designed to overcome the caveat inherited in LASSO when a group of variables is highly correlated. Both LASSO and the adaptive elastic net may yield the same outcome, which further strengthens the results. The elastic net assumes two penalty terms, which can be written in the following Lagrangian form:

$$\Sigma_{i=1}^{n} [y_i - \beta_0 - \Sigma_{j=1}^{p} \beta_j x_{ij}]^2 + \lambda_1 \Sigma_{j=1}^{p} |\beta_j| + \lambda_2 \Sigma_{j=1}^{p} |\beta_j|^2 . \tag{3}$$

Table 12 presents the results from feature selection techniques. Consistent with the results of the regressions in Tables 10 and 11, LASSO finds that TIPS discounts are mainly associated with marking-to-market concerns, as the estimated coefficient for marking-to-market concerns is 1.3632. In addition, the association between TIPS discounts and intermediation friction is substantial in the data, as the estimated coefficient for intermediate frictions is 1.0606; although, the association is not as large as that of marking-to-market concerns. The elastic net algorithm reveals the same results, further confirming the key variable set selected by LASSO. Taken together, the results suggest that the marking-to-market concerns is the main driver of TIPS discounts; though, intermediation frictions in the TIPS market also play a substantial role.

[Insert Table 12 Here]

4.6 Robustness of the results

We further implement the nonlinear iterative partial least squares (NIPALS) algorithm proposed by Wold (1975) to check the robustness of the results. We follow Wold (1994) and apply the variable-importance-in-projection (VIP) method to partial least squares (PLS) to obtain the cumulative measure of the influence of each potential determinant on TIPS discounts.

$$PLS - VIP = \left[K \times \frac{\sum_{i=1}^{7}(w_i^2 \times SSY_{comp,i})}{SSY_{cum}}\right]^{1/2} \quad (4)$$

where w_i is the PLS weight; $SSY_{comp,i}$ is the sum of the squared discount (i.e., the Y variable) explained by component i; SSY_{cum} is the total sum of squares explained by PLS; and K is the number of terms in the model. Hence, the VIP is the weighted sum of the squares of all components of the PLS weight. Explanatory variables with VIP values greater than 1 are considered the most relevant, whereas those with VIP values less than 0.5 are considered irrelevant.

[Insert Figure 4 Here]

Figure 4 presents a correlation loading plot summarizing the first two extracted factors, in which deviations represent TIPS discounts. Here, we consider Treasury inconvenience yield (direct holdings), Treasury inconvenience yield (indirect holdings), MOVE, SRVIX, TED, and repo specialness. The correlation loading plot offers many useful aspects of the two most significant dimensions of the correlation matrix of explanatory variables. The dots in the plot are highly centered and most of the observations are close together, implying that the first two factors can explain most variations.[16]

[16] If we see a curved pattern, we should consider a quadratic term. Multiple groupings of observations indicate that we might want to consider having classification effects in the estimation model.

The variable importance plot provides more straightforward information regarding the drivers that are the most useful for predicting the dependent variable. The variable importance plot visualizes Wold's (1994) "variable importance for projection" statistics, which captures how each explanatory variable contributes to fitting the PLS for predictors and responses. Wold (1994) considers a value less than 0.8 to be "small" for the VIP. Figure 5 shows that Treasury inconvenience yield (direct holdings), TED, MOVE, and SRVIX are key to predicting TIPS discounts. Given that the four variables are the major building blocks of "marking-to-market concerns" and "intermediation frictions" in Table 9, the results further ascertain that both marking-to-market concerns and intermediation frictions play a key role to understand the TIPS-Treasury bond puzzle.

[Insert Figure 5 Here]

4.7 Time-varying covariance structure

The documented empirical associations may vary over time. We further employ Bai and Perron's (1998, 2003) test for structural breaks and explore the time-varying covariance structure between the potential channels and TIPS discounts. For $j = 1, \dots, m + 1$, we adopt the following specification:

$$Y_t = \boldsymbol{Z}_t \delta_j + u_t, \tag{5}$$

where m is the number of structural breaks; $\boldsymbol{Y}$ is a column vector representing the dependent variable; $\boldsymbol{Z}$ is the covariates vector; δ_j is the coefficients vector for each subsample; and $\boldsymbol{u}$ is the disturbance term. The $Z_t\delta_j$ term implies that all covariates are subject to structural changes. We identify the breaks by sequentially solving the following optimization problem for each i = $1, \ldots, m$:

$$\Sigma_{i=1}^{m+1} \Sigma_{t=T_{i-1}+1}^{T_i} [Y_t - \boldsymbol{Z}_t \delta_j]^2. \tag{6}$$

We begin with the single-break case. We should be able to determine the first structural break that minimizes the sum of squared residuals in Eq. (6). We repeat this process sequentially to search for further breaks. However, a caveat of this approach is that we do not have prior information on the exact number of structural breaks. Hence, we employ double maximum tests, where the null hypothesis involves no break, and the alternative hypothesis involves an unknown number of breaks. The test statistic is:

$$D_{max} = \max_{n=1,\ldots,m} (a_n \; Sup \; F(0, n)). \tag{7}$$

where $F(0, n)$ denotes the standard F ratio test. If a_n is equal to 1 for all $n = 1, \ldots, m$, we conduct the UD_{max} test. Alternatively, if a_n is a function of the asymptotic critical values for $Sup \; F(0, n)$, the D_{max} statistic is called the WD_{max} test. In Table 13, both the UD_{max} and WD_{max} tests reject the null hypothesis at the 1% s level, implying multiple structural breaks. We identify at least five break days: March 2, 2015, October 10, 2015, January 8, 2018, May 6, 2019, and November 23, 2020. Table 13 summarizes the six regimes identified by the five structural break dates.

[Insert Table 13 Here]

We use the LASSO and elastic net to estimate the relative importance of the time-varying coefficients, i.e., δ_j, for each subsample. Table 14 presents the results. The results of LASSO, which are shown in Panel A of Table 14, are the same as those of the elastic net, which are shown in Panel B of Table 14. The loadings on marking-to-market concerns and intermediation frictions are indeed time-varying, and this fluctuating covariance structure is associated with TIPS discounts from Regime 1 to Regime 6. Marking-to-market concerns are persistently priced throughout the data span. Meanwhile, the role of intermediation frictions is salient in the mid-2010s, and its impact on TIPS discounts has recently improved.

[Insert Table 14 Here]

In summary, unlike other Treasury securities where the face value is fixed over time, the principal of a TIPS issue increases (or decreases in the case of deflation) in accordance with economic inflation. Although TIPS are designed to protect investors against inflation, the unique feature of the principal-adjusting mechanism indicates that one needs to hold a TIPS issue until maturity to get fully compensated against inflation. This restriction raises marking-to-market concerns when the economic situation is uncertain. Hence, although the TIPS-Treasury bond mispricing averages 3.18% per year, it does not disappear. The study's results suggest that when arbitrage is costly, asset prices may deviate from fundamental values for prolonged periods (Gemmill and Thomas, 2002).

5. Concluding Remarks

TIPS are usually undervalued compared to cash flow-matched Treasury bonds. We use J.P. Morgan's proprietary asset swap data to explore the factors associated with TIPS discounts. We also quantify the relative importance of potential drivers regarding the magnitude of the price gaps between TIPS and Treasury bonds. Our study shows that uncertainty-related variables are key to understanding the underpricing of TIPS issues compared to their hypothetical counterparts. We conclude that when strategic concerns, e.g., marking to market concerns, overwhelm fundamental analysis, asset prices may deviate from fundamental values for prolonged periods.

In real terms, Treasury coupon securities are risky. Treasury bills are risky to long-term investors. Inflation-indexed securities fill this gap, as they offer several benefits. First, TIPS protect investors against inflation. TIPS facilitate investors' portfolio choices and address market participants' concerns regarding inflation. Second, TIPS enable issuers to save on the inflation risk premium inherent in nominal issuances. However, these benefits are yet to be realized, as TIPS discounts remain in a prolonged horizon. Persistent TIPS discounts offset the advantage of bearing no inflation risk premium as issuers incur additional borrowing costs, even if liquidity significantly improves as the market matures. Our results suggest that intermediary frictions and strategic concerns may better moderate the TIPS-Treasury bond puzzle.

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Table 1: Empirical proxies for the potential drivers of the TIPS-Treasury bond puzzle

This table presents the drivers of the TIPS-Treasury bond puzzle. Proxies are classified into two categories: a) intermediation friction and b) strategic concerns. The table below includes various abbreviations defined as follows: OIS = overnight index swap, GC repo = general collateral repo rates, LIBOR = London Inter-Bank Offered Rate, and DTCC = the Depository Trust and Clearing Corporation. DTCC GC repo rates are available at https://www.dtcc.com/charts/dtcc-gcf-repo-index#download and the Bank of New York Mellon tri-party repo rates are from https://repoindex.bnymellon.com/repoindex/. We follow CBOE's SRVIX white paper to replicate the index. Replication resources are available at https://cdn.cboe.com/resources/indices/srvix-white-paper.pdf.

Category	Driver	Definition	Timespan	Remarks
Intermediation Frictions	Intermediaries' direct book cost	10-year Treasury minus 10-year OIS	Jan. 2005 ~ Dec. 2022	J.P. Morgan
	Intermediaries' indirect book cost	GC repo rate minus Tri-Party repo rate	Aug. 2012 ~ Dec. 2022	GC repo rates from DTCC and Tri-Party repo rates from Bank of New York Mellon
	Funding Liquidity	3-month LIBOR minus 3-month T-Bill	Jan. 2005 ~ Dec. 2022	J.P. Morgan
	Repo Specialness	GC repo rate minus On-the-run Treasury Special Repo Rate	Jan. 2005 ~ Dec. 2022	GC repo rates from DTCC and special repo rates from J.P. Morgan
Strategic Concerns	Ex-ante bond option volatility	MOVE index	Jan. 2005 ~ Dec. 2022	Bloomberg
	Ex-ante swaption market volatility	SRVIX index	Jan. 2005 ~ Dec. 2022	Own calculation using swaption data provided by J.P. Morgan

Table 2: Mechanism for replicating a synthetic bond

This table describes Fleckenstein et al.'s (2014) replication strategy to create a synthetic nominal Treasury. The key differences between nominal Treasuries and TIPS are two-fold. First, the face value of TIPS increases in accordance with the Urban CPI. Second, the TIPS coupon payments are adjusted by the CPI figures. P denotes the dirty price of a Treasury bond with a face value of 100, while paying C as coupons. Similarly, V represents the dirty price of a TIPS with a face value of 100 at issuance, while paying R as coupons. I_t equals the CPI index at time t divided by the initial CPI at time zero. A zero-coupon inflation swap buyer pays a compounded fixed rate K_t and receives I_t at time t. D_t represents the unit price of STRIPS maturing at time t.

	Nominal Treasury			**Synthetic Treasury**		
	Upfront at Inception	**Semi-annual Payments**	**at Maturity**	**Upfront at Inception**	**Semi-annual Payments**	**at Maturity**
Treasury	$-P$	$+C$	$C + 100$			
TIPS				$-V$	$+R \cdot I_t$	$+(R + 100) \cdot I_T$
Inflation Swap					$+R \cdot (K_t - I_t)$	$+(R + 100) \cdot (K_T - I_T)$
STRIPS				$-\sum_{i=1}^{i=T}(C - R \cdot K_i) \cdot D_i - 100 \cdot (1 - K_T) \cdot D_T$	$C - R \cdot K_t$	$(C - R \cdot K_T) + 100 \cdot (1 - K_T)$
Net Cash Flows	$-P$	$+C$	$C + 100$	$-\sum_{i=1}^{i=T}(C - R \cdot K_i) \cdot D_i - 100 \cdot (1 - K_T) \cdot D_T - V$	$+C$	$C + 100$

Table 3: Mechanism of asset swaps

This table illustrates the mechanics of our approach, which creates two floating-rate notes using asset swaps. In the U.S., inflation linkers are typically traded as the proceeds of an asset swap, which adjusts its notion for accrued inflation. For comparability, nominal Treasuries are expressed in the form of a proceeds asset swap. P denotes the dirty price of a treasury bond with a face value of 100, while paying C as coupons. Similarly, V represents the dirty price of a TIPS with a face value of 100 at issuance, while paying R as coupons. I_t equals the CPI index at time t divided by the initial CPI index at time zero. A zero-coupon inflation swap buyer pays a compounded fixed rate K_t and receives I_t at time t. LIBOR is the acronym of London Inter-Bank Offered Rate. N refers to the asset swap spread for a nominal Treasury bond. L represents the asset swap spread for a TIPS issue.

	Asset Swapped Nominal Treasury			**Asset Swapped Inflation Linker**		
	Upfront at Inception	**Semi-annual Payments**	**at Maturity**	**Upfront at Inception**	**Semi-annual Payments**	**at Maturity**
Treasury	$-P$	$+C$	$C+100$			
TIPS				$-V$	$+R \cdot I_t$	$+(R+100) \cdot I_T$
Asset Swap (fixed)	$+P$	$-C$	$-(C+100)$	$+V$	$-R \cdot I_t$	$-(R+100) \cdot I_T$
Asset Swap (floating)	$-P$	$+(LIBOR+N) \cdot P$	$+P$	$-V$	$+(LIBOR+L) \cdot V$	$+V$
Net Cash Flows	$-P$	$+(LIBOR+N) \cdot P$	$+P$	$-V$	$+(LIBOR+L) \cdot V$	$+V$

Table 4: Summary statistics

We aggregate the daily data from January 4, 2010 to December 30, 2022 by week and compute weekly averages to minimize market microstructural noise and house-specific idiosyncrasies. We winsorize the variables at the 1% and 99% levels to mitigate the impact of outliers on the results. N denotes the number of observations. Std. Dev. denotes the standard deviation. Deviation refers to the 10-year Treasury asset swap spreads minus the 10-year TIPS asset swap spreads. TIY (Direct Holdings) represents intermediaries' book costs for the direct holding of securities and is measured as 10-year Treasury minus 10-year OIS rates. TIY (Indirect Holdings) denotes intermediaries' indirect book costs and is measured as GC repo rate minus the triparty repo rate. MOVE represents the implied Treasury bond option volatility. SRVIX proxies for ex-ante swap market volatility implied from swaption prices. TED is 3-month LIBOR minus 3-month T-bill. Repo specialness is GC repo rate minus on-the-run Treasury special repo rate.

	N	**Mean**	**Std. Dev.**	**Min**	**P25**	**Median**	**P75**	**Max**
Deviation	677	8.32	2.61	3.10	6.56	8.02	9.70	19.49
TIY (Direct Holdings)	665	7.78	3.50	2.38	5.27	7.01	9.66	19.64
TIY (Indirect Holdings)	536	2.23	1.99	-1.35	0.97	1.95	3.16	9.51
MOVE	635	23.01	7.96	12.32	17.01	21.54	26.86	64.32
SRVIX	677	29.11	7.48	19.10	23.57	26.99	33.37	59.82
TED	669	8.56	4.71	2.33	5.44	7.37	10.66	43.24
Repo Specialness	669	9.12	14.11	-2.30	-2.23	4.70	9.58	96.80

Table 5: Correlation coefficients

We aggregate the daily data from January 4, 2010 to December 30, 2022 by week and compute weekly averages to minimize market microstructural noise and house-specific idiosyncrasies. N denotes the number of observations. P-values are shown in square brackets. *, **, and *** represent significance at the 10%, 5%, and 1% levels, respectively. Deviation refers to 10-year Treasury asset swap spreads minus 10-year TIPS asset swap spreads. TIY (Direct Holdings) represents intermediaries' book costs for direct holding of securities and is measured as 10-year Treasury minus 10-year OIS rates. TIY (Indirect Holdings) denotes intermediaries' indirect book costs and is measured as GC repo rate minus the triparty repo rate. MOVE represents the implied Treasury bond option volatility. SRVIX proxies for ex-ante swap market volatility implied from swaption prices. TED is 3-month LIBOR minus 3-month T-bill. Repo specialness is GC repo rate minus on-the-run Treasury special repo rate.

	Deviation	TIY (Direct Holdings)	TIY (Indirect Holdings)	MOVE	SRVIX	TED	Repo Specialness
Deviation	1.0000	0.4515*** [<0.0001]	0.2894*** [<0.0001]	0.5401*** [<0.0001]	0.6433*** [<0.0001]	0.4360*** [<0.0001]	0.1281*** [0.0009]
TIY (Direct Holdings)		1.0000	0.6009*** [<0.0001]	0.0670* [0.0947]	0.0850** [0.0284]	0.4853*** [<0.0001]	0.2854 [<0.0001]
TIY (Indirect Holdings)			1.0000	-0.1446*** [0.0012]	-0.0584 [0.1765]	0.3593*** [<0.0001]	0.3157*** [<0.0001]
MOVE				1.0000	0.8909*** [<0.0001]	0.3365*** [<0.0001]	-0.0134 [0.7358]
SRVIX					1.0000	0.2916*** [0.0001]	-0.0402*** [0.2973]
TED						1.0000	0.1129 [0.0035]
Repo Specialness							1.0000

Table 6: Univariate regressions with controls

This table summarizes the univariate regression results for the deviation in Eq. (1). Deviation refers to 10-year Treasury asset swap spreads minus 10-year TIPS asset swap spreads. TIY (Direct Holdings) represents intermediaries' book costs for direct holding of securities and is measured as 10-year Treasury minus 10-year OIS rates. TIY (Indirect Holdings) denotes intermediaries' indirect book costs and is measured as GC repo rate minus tri-party repo rate. MOVE represents implied Treasury bond option volatility. SRVIX proxies for ex-ante swap market volatility implied from swaption prices. TED is 3-month LIBOR minus 3-month T-bill. Repo specialness is GC repo rate minus on-the-run Treasury special repo rate. Controls include the return on the S&P 500 index, VIX, and Moody's seasoned Baa corporate bond yield relative to the yield on the 10-year Treasury constant maturity (BAA10Y-CMT10Y). We aggregate the daily data from January 4, 2010 to December 30, 2022 by week and compute weekly averages to minimize market microstructural noise and house-specific idiosyncrasies. N denotes the number of observations. Heteroscedasticity-consistent test statistics are shown in square brackets. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	Dependent variable: *Deviation*					
TIY (Direct Holdings)	0.2850*** [11.08]					
TIY (Indirect Holdings)		0.2571*** [4.40]				
MOVE			0.1500*** [11.57]			
SRVIX				0.2052*** [15.03]		
TED					0.1582*** [3.90]	
Repo Specialness						0.0193*** [2.79]
Return on the S&P500 index	-40.1251 [-0.83]	21.9578 [0.38]	-49.7782 [-1.24]	-45.9139 [-1.36]	-52.9971 [-0.96]	-40.2568 [-0.78]
VIX	0.1645*** [2.85]	0.0960 [2.15]	-0.1078** [-2.09]	-0.0354 [-0.94]	0.0409 [0.66]	0.1201** [2.03]
BAA10Y-CMT10Y	3.9312*** [7.66]	3.3525*** [5.34]	3.7630*** [7.29]	1.5033*** [2.98]	4.2460*** [7.20]	5.1975*** [9.68]
N	660	533	631	672	664	671
F statistic	93.62***	27.36***	84.36***	122.88***	66.86***	51.14***
R-Square	0.3638	0.1717	0.3502	0.4243	0.2887	0.2350

Table 7: Univariate regressions with fixed effects

This table presents univariate regression results with year-month fixed effects. We aggregate the daily data from January 4, 2010 to December 30, 2022 by week and compute weekly averages to minimize market microstructural noise and house-specific idiosyncrasies. Deviation refers to 10-year Treasury asset swap spreads minus 10-year TIPS asset swap spreads. TIY (Direct Holdings) represents intermediaries' book costs for direct holding of securities and is measured as 10-year Treasury minus 10-year OIS rates. TIY (Indirect Holdings) denotes intermediaries' indirect book costs and is measured as GC repo rate minus Tri-party repo rate. MOVE represents implied Treasury bond option volatility. SRVIX proxies ex-ante swap market volatility implied from swaption prices. TED is 3-month LIBOR minus 3-month T-Bill. Repo specialness is GC repo rates minus on-the-run Treasury special repo rates. N denotes the number of observations. Heteroscedasticity-consistent test statistics are shown in square brackets. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	Dependent variable: *Deviation*					
TIY (Direct Holdings)	0.7995*** [26.26]					
TIY (Indirect Holdings)		0.6583*** [9.84]				
MOVE			0.2909*** [32.22]			
SRVIX				0.2747*** [44.66]		
TED					0.4478*** [17.15]	
Repo Specialness						0.0235*** [3.75]
Year-month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
N	665	536	635	677	669	674
F statistic	20.47***	9.53***	26.96***	45.91***	12.51***	7.03***
R-Square	0.8627	0.7459	0.8979	0.9323	0.7921	0.6794

Table 8: Eigenvalues of the correlation matrix

This table presents the results of the principal component analysis. We aggregate the daily data from January 4, 2010 to December 30, 2022 by week and compute weekly averages to minimize market microstructural noise and house-specific idiosyncrasies. We consider the following six variables: TIY (direct holdings), TIY (indirect holdings), MOVE, SRVIX, TED, and repo specialness. TIY (Direct Holdings) represents intermediaries' book costs for the direct holding of securities and is measured as 10-year Treasury minus 10-year OIS rates. TIY (Indirect Holdings) denotes intermediaries' indirect book costs and is measured as GC repo rate minus tri-party repo rate. MOVE represents the implied Treasury bond option volatility. SRVIX proxies for ex-ante swap market volatility implied from swaption prices. TED is 3-month LIBOR minus 3-month T-bill. Repo specialness is GC repo rates minus on-the-run Treasury special repo rate.

	Eigenvalue	Difference	Proportion	Cumulative
1	2.3378	0.4882	0.3896	0.3896
2	1.8496	0.9967	0.3083	0.6979
3	0.8529	0.3649	0.1422	0.8400
4	0.4880	0.1204	0.0813	0.9214
5	0.3676	0.2635	0.0613	0.9826
6	0.1041		0.0174	1.0000

Table 9: Varimax-rotated factor patterns

This table describes the principal components of the varimax-rotated covariance matrix for TIY (direct holdings), TIY (indirect holdings), MOVE, SRVIX, TED, and repo specialness. TIY (Direct Holdings) represents intermediaries' book costs for the direct holding of securities and is measured as 10-year Treasury minus 10-year OIS rates. TIY (Indirect Holdings) denotes the intermediaries' indirect book costs and is measured as GC repo rates minus tri-party repo rates. MOVE represents the implied Treasury bond option volatility. SRVIX proxies for ex-ante swap market volatility implied from swaption prices. TED is 3-month LIBOR minus 3-month T-bill. Repo specialness is GC repo rates minus on-the-run Treasury special repo rates. We use one as the threshold of eigenvalues. The first two principal components satisfy this threshold value criterion. The values are rounded to the nearest integer after multiplying by 100. An asterisk is placed on values greater than 0.5.

	Factor 1	Factor 2
TIY (Direct holdings)	19	83*
TIY (Indirect holdings)	-16	85*
MOVE	96*	-3
SRVIX	95*	0
TED	48	58*
Repo Specialness	-5	57*

Table 10: Multivariate regressions with controls

This table summarizes the multivariate regression results for the TIPS discounts. Deviation refers to the 10-year Treasury asset swap spreads minus the 10-year TIPS asset swap spreads. Controls include the return on the SP 500 index, the VIX, and Moody's seasoned Baa corporate bond yield relative to the yield on the 10-year Treasury constant maturity (BAA10Y-CMT10Y). We aggregate the daily data from January 4, 2010 to December 30, 2022 by week and compute weekly averages to minimize market microstructural noise and house-specific idiosyncrasies. N denotes the number of observations. The heteroscedasticity-consistent test statistics are shown in square brackets. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	Dependent variable: Deviation		
Marking-to-market concerns	1.4320*** [14.38]		1.5545*** [15.78]
Intermediation frictions		1.1100*** [10.81]	1.1057*** [12.28]
Return on the S&P500 index	-44.3135 [-1.23]	18.3376 [0.31]	5.6291 [0.16]
VIX	-0.0933** [-2.14]	0.0992 [1.46]	-0.0970** [-2.13]
BAA10Y-CMT10Y	2.5395*** [5.01]	1.8966 [3.39]	-0.8172 [-1.54]
N	631	678	481
F statistic	103.53***	55.54***	101.98***
R-square	0.3982	0.3010	0.5177

Table 11: Multivariate regressions with fixed effects

This table displays the multivariate regression results with year-month fixed effects. We aggregate the daily data from January 4, 2010 to December 30, 2022 by week and compute weekly averages to minimize market microstructural noise and house-specific idiosyncrasies. N denotes the number of observations. Heteroscedasticity-consistent test statistics are shown in square brackets. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	Dependent variable: Deviation		
Marking-to-market concerns	2.1926*** [39.10]		1.9059*** [25.69]
Intermediation frictions		2.2312*** [20.61]	0.5029*** [5.20]
Year-month fixed effects	Yes	Yes	Yes
N	635	524	484
F statistic	36.67***	17.95***	50.49***
R-square	0.9228	0.8507	0.9473

Table 12: Feature selection techniques

This table summarizes the results from feature selection techniques. Both variables are normalized using sample mean and standard deviation. We aggregate the daily data from January 4, 2010 to December 30, 2022 by week and compute weekly averages to minimize market microstructural noise and house-specific idiosyncrasies. N denotes the number of observations. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

	Dependent variable: Deviation	
	LASSO	Elastic Net
Marking-to-market concerns	1.3632	1.3632
Intermediation frictions	1.0303	1.0303
N	484	484
F-statistic	245.30***	245.30***
R-square	0.5049	0.5049

Table 13: Bai and Perron's (1998, 2003) test for structural breaks

This table summarizes the results of Bain and Perron's (1998, 2003) test for structural breaks. Std. Dev. denotes the standard deviation. IQR is interquartile range. We aggregate the daily data from August 1, 2012, to December 30, 2022 by week and compute weekly averages to minimize market microstructural noises and house-specific idiosyncrasies. TIPS discounts are in basis points.

Regime	Sample span	TIPS discounts (bps)			
		Mean	Std. Dev.	Min	Max
1	Aug. 1, 2012 ~ Feb. 27, 2015	7.94	1.91	3.10	13.32
2	Mar. 2, 2015 ~ Oct. 7, 2016	7.56	2.46	3.84	14.94
3	Oct. 10, 2016 ~ Jan. 5, 2018	10.31	2.10	7.40	16.75
4	Jan. 8, 2018 ~ May 3, 2019	8.30	1.48	5.92	12.20
5	May 6, 2019 ~ Nov. 20, 2020	7.02	1.59	4.75	12.00
6	Nov. 23, 2020 ~ Dec. 30, 2022	7.42	3.39	3.10	16.84

Table 14: Subsample analysis

This table presents the results of the LASSO regression and the elastic net methods for each subsample listed in Table 12. We aggregate the daily data from January 4, 2010 to December 30, 2022 by week and compute weekly averages to minimize market microstructural noises and house-specific idiosyncrasies. N denotes the number of observations. Heteroscedasticity-consistent test statistics are shown in square brackets. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.

Panel A: The LASSO method

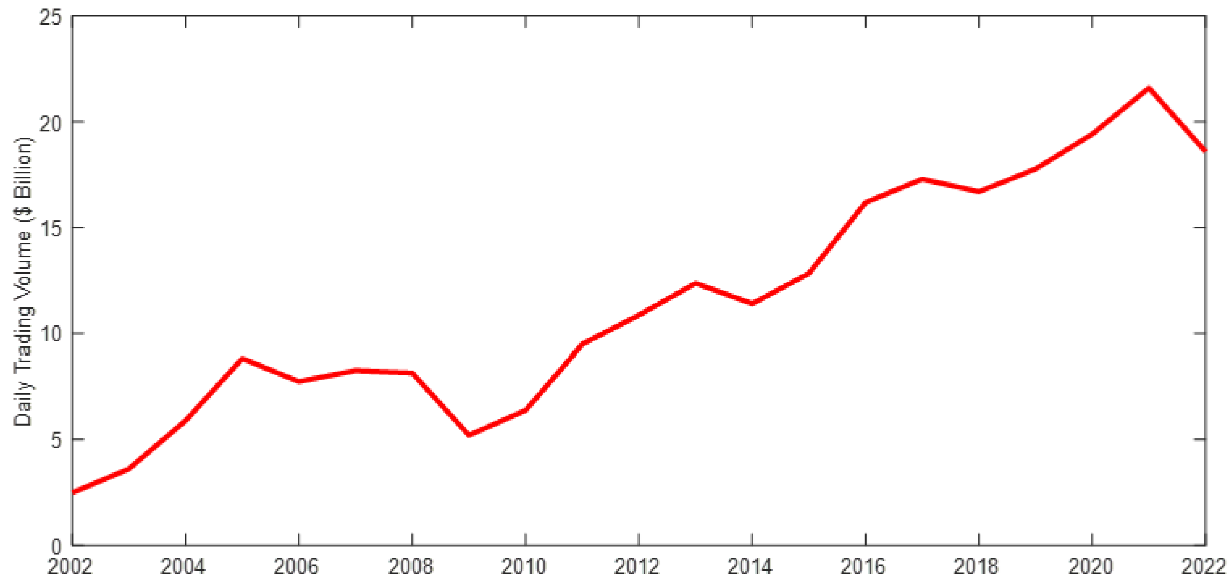
	Regime 1	Regime 2	Regime 3	Regime 4	Regime 5	Regime 6
Marking-to-market concerns	1.9567	0.8038	2.2167	2.3638	2.4216	2.1489
Intermediation frictions		1.4515	0.7103	0.2275		0.7147
N	106	78	54	62	90	94
F statistic	116.64***	55.42***	144.43***	175.69***	35.00***	268.65***
R-square	0.5286	0.5964	0.8499	0.8562	0.4459	0.8552

Panel B: The elastic net

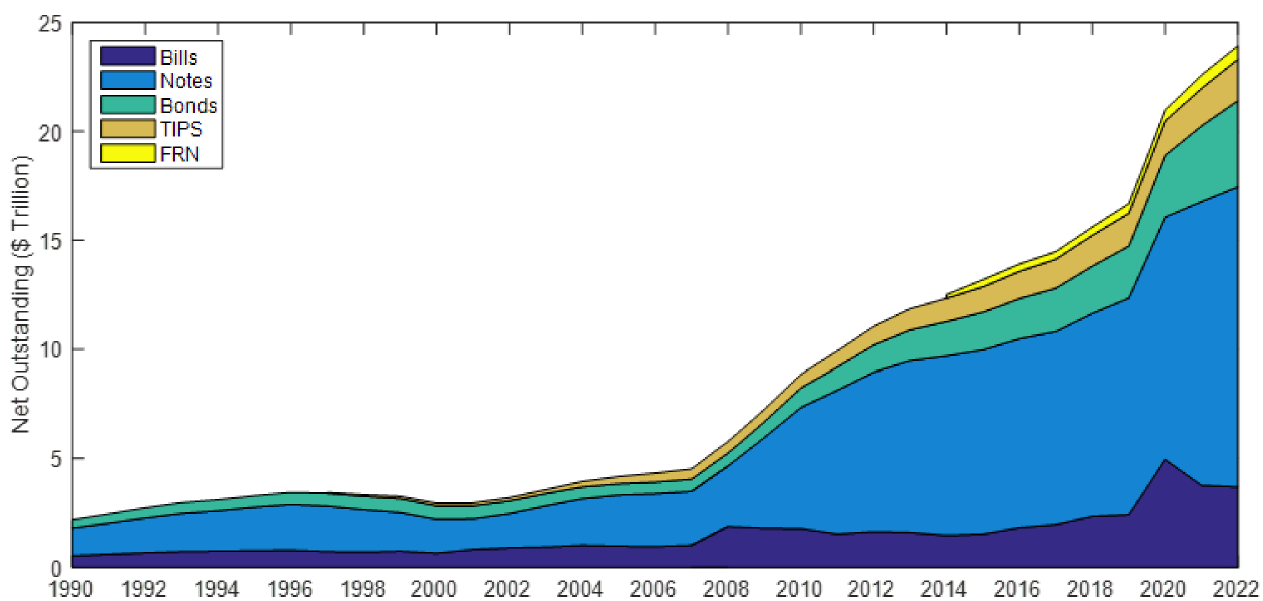
	Regime 1	Regime 2	Regime 3	Regime 4	Regime 5	Regime 6
Marking-to-market concerns	1.9567	0.8038	2.2167	2.3638	2.4216	2.1489
Intermediation frictions		1.4515	0.7103	0.2275		0.7147
N	106	78	54	62	90	94
F statistic	116.64***	55.42***	144.43***	175.69***	35.00***	268.65***
R-square	0.5286	0.5964	0.8499	0.8562	0.4459	0.8552

Figure 1: TIPS trading volume and outstanding notional

Figure 1a represents the average daily trading volume of TIPS by primary dealers, and Figure 1b illustrates the outstanding notional of U.S. Treasury marketable securities. The data are reported by the Federal Reserve Bank of New York and the statistics are tabulated by the Securities Industry and Financial Markets Association (SIFMA).



(a) TIPS trading volume



(b) TIPS outstanding concept.

Figure 2: Market-based inflation measures (BEI vs. inflation-linked swap rate)

Figure 2 presents the two proxies for the market-based inflation measures. BEI refers to the differences between nominal and TIPS rates, where nominal yields are 10-year constant maturity Treasury yields and TIPS yields are 10-year TIPS real yields. Inflation swap rates are the strike rates quoted in over-the-counter markets. Data are from J.P. Morgan and are tabulated on a daily basis. Data are from Jul. 14, 2006 to 2022.

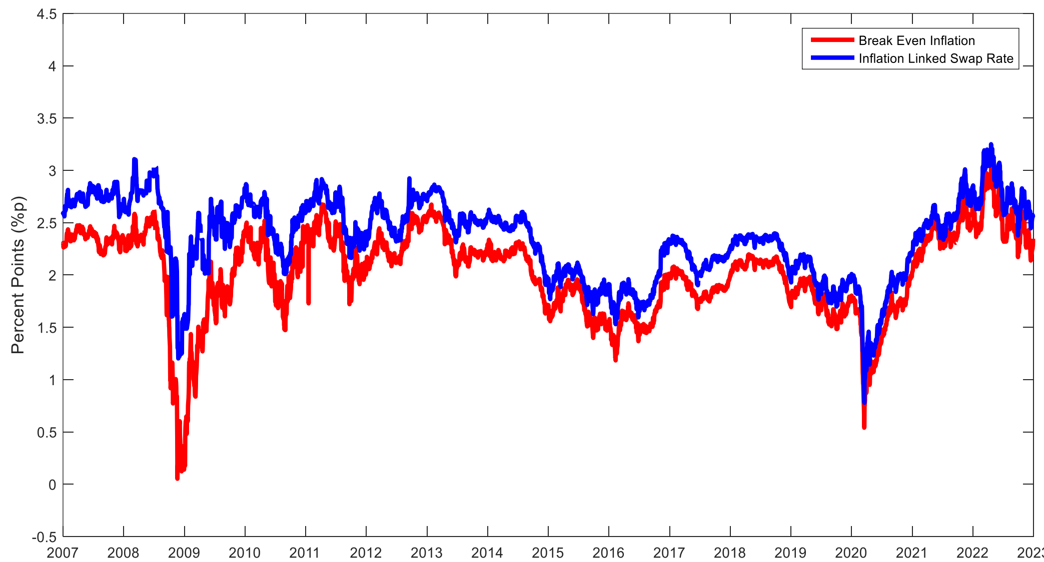


Figure 3: Asset swap spreads

Figure 3 depicts the asset swap spreads of 10-year TIPS and maturity-matched nominal Treasury, which are added to the LIBOR rates. Asset swap spreads are provided by J. P. Morgan and are tabulated on a daily basis. The dataset covers the 2005-2022 period.

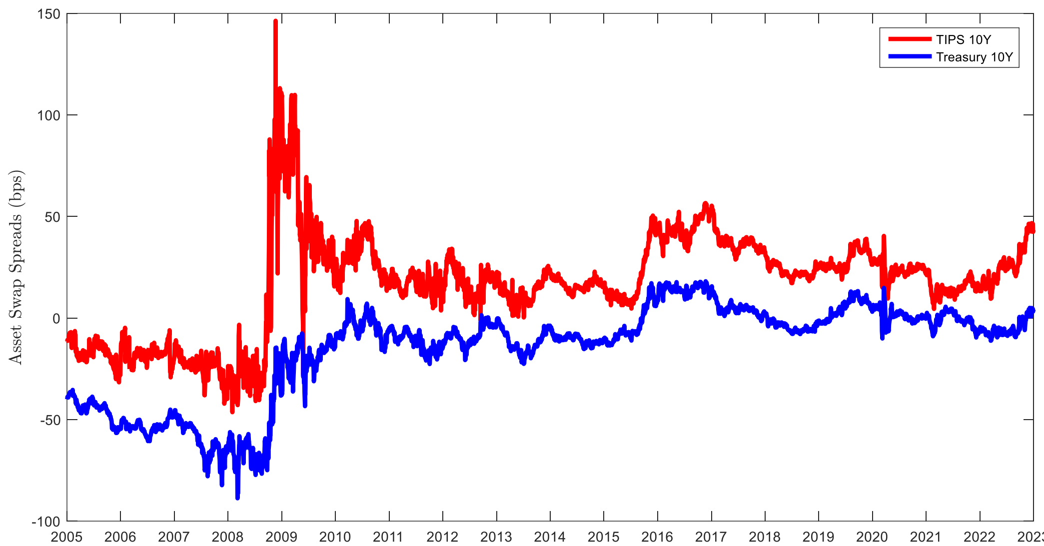


Figure 4: Correlation loading plot

Figure 4 presents a correlation loading plot that summarizes the first two extracted factors, in which deviations represent TIPS discounts. We consider Treasury inconvenience yield (direct holdings), Treasury inconvenience yield (indirect holdings), MOVE, SRVIX, TED, and repo specialness. The dots in the plot represent the scores for the first two factors. We aggregate the daily data from January 4, 2010 to December 30, 2022 by week and compute weekly averages to minimize market microstructural noises and house-specific idiosyncrasies.

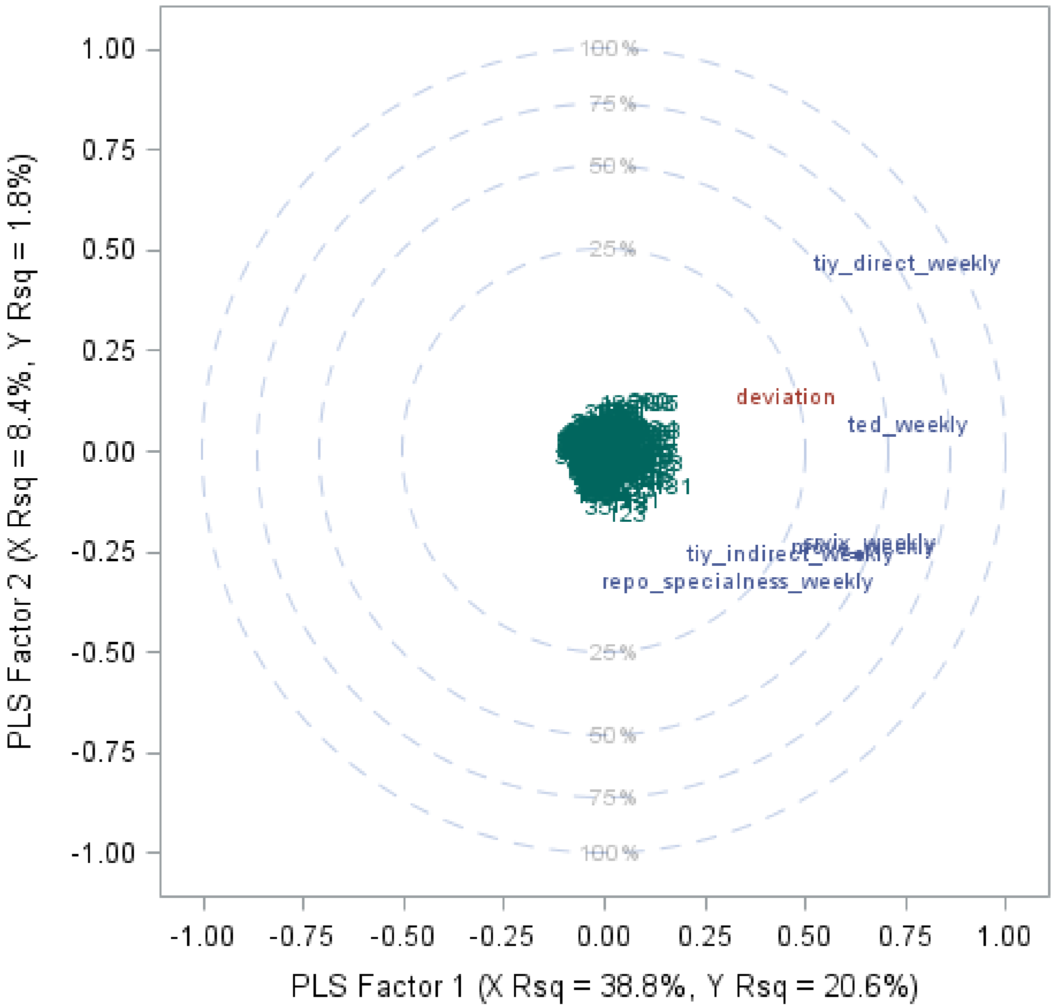


Figure 5: Variable importance plot

We consider Treasury inconvenience yield (direct holdings), Treasury inconvenience yield (indirect holdings), MOVE, SRVIX, TED, and repo specialness. The dots in the plot represent the scores for the first two factors. We aggregate the daily data from January 4, 2010 to December 30, 2022 by week and compute weekly averages to minimize market microstructural noises and house-specific idiosyncrasies.