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Nominal U.S. Treasuries Embed Liquidity Premiums, Too

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Abstract

A novel arbitrage-free model of nominal U.S. Treasuries that decomposes yields into frictionless expected rates, frictionless term premiums, and liquidity premiums produces four key results from Jan. 1987 to Aug. 2023. First, liquidity loadings are larger than for the slope and higher-order principal components. Second, the countercyclicality of required nominal Treasury returns owes to liquidity, if anything, not frictionless term premiums. Third, Federal Reserve large-scale asset purchases generally work through expected rates and frictionless term premiums, not liquidity premiums. Fourth, given similar estimates using TIPS, inflation expectations are less moored around the Federal Reserve's price objectives than other models say.

I. Introduction

A hackneyed observation about the nominal U.S. Treasury (UST) market is that it is among the deepest and most liquid. A handful of foreign exchange pairs might rival U.S. government bonds on that score. Nonetheless, commentators routinely reference USTs as the global safe-haven asset. This easy characterization of Treasury liquidity fully seeps into empirical specifications of arbitrage-free, affine term structure models (ATSMs). Besides isolating violations of the law of one price, these models also allow central bankers and investors alike to disentangle expected short rates and term premiums—aka required excess returns—from observed yields. A fundamental assumption beyond ubiquitous risk-free borrowing, shared by the Black-Scholes-Merton option pricing model, is the ability to trade without "friction" (i.e., in any quantity without affecting prices). Admittedly, USTs might be the most natural application of arbitrage-free models, insofar as the asset class may be as close to the mythical frictionless security as any.

The argument below is not that USTs are any less liquid in comparative terms, or any worse an application for arbitrage-free models, even. And yet, policymakers and investors most keenly monitor these models during extreme episodes. The experiences of say, the fall of 1998, the global financial crisis (GFC), and trading activity in Mar. 2020 during the worst of the COVID-19 market rout, all comprise

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episodes of, again not necessarily comparative, but clearly absolute deteriorations in Treasury market functioning. Unfortunately, with precious few (e.g., Fontaine and Garcia (2012)) and only partial exceptions (e.g., Abraham, Adrian, Crump, Moench, and Yu (AACMY) (2016)), and despite analyses of plausibly time-varying "convenience yields" compared to other assets that owe in part to liquidity on nominal Treasuries (Krishnamurthy and Vissing-Jorgensen (2012)), the vast literature on ATSMs ignores absolute liquidity risk in nominal USTs altogether, including Kim and Wright (KW) (2005), Kim and Orphanides (2012), and Adrian, Crump, and Moench) (ACM) (2013), say. Also, ATSMs that incorporate TIPS readily relax the frictionless assumption for inflation-linked bonds but nonetheless look the other way on nominal USTs (e.g., D'Amico, Kim, and Wei (DKW) (2018)).

The objective of this study is to parse further compensation for owing USTs into time-varying "frictionless" term and nominal liquidity premiums. The proposed model embeds a novel observable liquidity factor (LF) for nominal USTs, distinct from latent-factor approaches (e.g., Fontaine and Garcia (2012)), using a wealth of information from fitted term structures of individual CUSIPs daily from Jan. 2, 1987, to Sept. 1, 2023. The remaining model factors include the first four principal components of the yield curve that are orthogonal to this LF, and estimation otherwise closely follows the linear-regression-based algorithm outlined in ACM.

Four empirical findings are noteworthy. First, negative average estimated nominal UST liquidity premiums, broadly consistent with convenience, belie considerable temporal variation as well as substantial effects on yields. Although less than the level of the term structure, not surprisingly, the yield as well as excess return loadings on the LF are greater than for the remaining factors, including the slope. This result suggests that standard ATSM applications that assume nominal USTs trade without friction may be meaningfully misspecified.

Second, the more detailed decomposition affords new insights into compensation for holding nominal USTs. Namely, the increase during the GFC in some estimates of "gross" term premiums owes entirely to an intuitive sharp spike in liquidity premiums and a corresponding drop in required excess returns on the frictionless-default-risk-free asset. More formally, econometrics suggest that any consistent countercyclicality in required nominal returns owes to compensation for liquidity risk. Trading frictions aside, and on the other side of the decompositions, nominal bond premia depend on relative perceptions of supply and demand shocks. Perforce, the cyclicality of frictionless term premiums is more demonstrably ambiguous.

Third, this finer parsing of required returns affords a reassessment of the effects of large-scale asset purchases (LSAPS) and addresses the literature stemming from Gagnon, Raskin, Remache, and Sack (2011), which rest on more limited decompositions. Alternative methodologies suggest that if anything LSAPs generally work through frictionless term premiums by way of portfolio rebalancing, and even anticipated short rates perhaps via "signaling," not market liquidity premiums on average. Inconclusive empirical results for liquidity premium responses may reflect corresponding theoretical ambiguity. LSAPs strictly reduce free float and boost nonborrowed reserves but may not lower trading costs.

Fourth, together with a similar decomposition of TIPS yields into expected real rates, real term premiums, and TIPS liquidity premiums—notably also using observable rather than latent factors and without any nonmarket information (Durham (2023))—these estimates of nominal USTs also provide an alternative lens on expected inflation, netting out frictionless inflation risk premiums and the quantity and price of risk across nominal USTs and TIPS. Compared to other approaches, such as DKW or AACMY, the results suggest that inflation expectations were substantially unmoored to the downside in the aftermath of the GFC, as well as to the upside at times in the wake of persistent inflationary pressures stemming from COVID-19. Despite sole reliance on nominal UST and TIPS quotes, again, a distinguishing feature of this approach, exclusively frictionless inflation expectations correlate reasonably with survey-based expectations.

The organization of this study is as follows: Section II details the liquidity index. Section III outlines the arbitrage-free framework, documents the salience of the LF, and discusses the nominal yield decompositions. Section IV covers premia cyclicality, LSAP effects, and expected inflation. Section V concludes.

II. Toward an Observable LF for Nominal USTs

Liquidity narrowly refers to trading costs. Yet the term also commonly and sweepingly refers to any frictions that cause deviations from the law of one price. Amid great conceptual ambiguity and measurement challenges, some studies address the positive bias in TIPS as readings on unobservable real yields that traces to their comparative illiquidity, whereas the assumption that nominal Treasuries embed no such premium in ATSMs is nearly ubiquitous.

To begin with a key methodological choice, as for all pricing factors in ATSMs, two alternative estimation strategies include latent-factor and observable-factor approaches to capturing liquidity risk. As an example of the former, and as a rare assessment of nominal UST liquidity premiums using ATSMs, Fontaine and Garcia (2012) identify a premium, which they characterize as a funding liquidity proxy. Briefly, they fit an ATSM with a nonlinear Kalman filter using 22 nominal USTs paired at 11 maturity bins from 3 to 120 months using monthly data, where the pairs include the most recent issue and the security that most closely matches the maturity of the bin.[1] Fontaine and Garcia (2012) report meaningful and persistent effects of their funding liquidity proxy on Treasury returns as well as risk premiums on LIBOR loans, swaps, and corporate bonds, but they do not disentangle liquidity premiums from ex ante frictionless term premiums. Another application of latent factors, although solely germane to TIPS, includes DKW. They capture a TIPS-specific factor likely related to liquidity, derived after "pre-estimation" steps from a Kalman filter estimate, which simultaneously produces time series for the other model factors as well as the model parameter estimates consistent with minimized pricing errors across nominals and TIPS.

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[1] Fontaine and Garcia (2012) impose parameter restrictions on the risk-neutral dynamics to preserve a Nelson–Seigel factor loading structure, a parsimonious but arguably a less flexible approach than the framework outlined below.

The alternative to latent factors is to use observable measures, data-reducing indices of proxies across different dimensions of market frictions, which arguably are more transparent and simpler than filtering methods. Observable measures may add welcome specificity around such a slippery concept, and as detailed below, factor construction can embed information from other dimensions of liquidity, beyond the narrow emphasis on seasoning as in Fontaine and Garcia (2012), say. An example under this alternative includes AACMY, who like DKW jointly estimate an ATSM of nominal USTs and TIPS. They construct an observable LF from two variables that comprise one of six factors that price all Treasuries. AACMY do formally allow for nominal UST exposure to their LF, yet notably their index factor only references TIPS liquidity.

The objective is not to settle this methodological score. Both have uses. Although tellingly researchers appear compelled to document the correlation between estimated latent factors and observable variables, anyway.[2] Moreover, given the absence of an observable nominal USTs LF in previous studies, the following model embeds such a factor, comprised of some metrics routinely applied to TIPS, like AACMY and Durham (2023). To start, the index includes fitting errors based on daily Nelson-Siegel-Svensson (NSS) yield curves, such as the estimates shown in Graph A of Figure 1. As Hu, Pan, and Wang (2013) (HPW) argue, large average misses capture times when arbitrage limits bind investors who cannot secure funding to exploit mispricings.[3] But to construct a richer set of observables, and to expand on recent extensions to TIPS (Durham (2023)), the following incorporates four addenda to the fitting-error lens on liquidity.

First, studies ubiquitously reference errors relative to NSS curves (AACMY, Christensen and Rudebusch (2019), DKW, Grishchenko and Huang (2013), and Andreasen, Christensen, and Riddell (2021)). However, this parametric form is unlikely the preferred tool of arbitragers, the very individuals whose constraints liquidity proxies endeavor to capture.[4] Therefore, this application also uses the variance roughness penalty (VRP) methodology (Wagoneer (1997), Anderson and Sleath, (1999)) and a recent machine learning or kernel regression (KR) approach (Filipovic, Markus, and Ye (2023)) as robustness checks. Graph A of Figure 1 also

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[2] For example, DKW regress their latent variable on a battery of observable proxies and report R^2 values of up to 0.848.

[3] Following HPW, the (unconditional) noise measure is the mean-squared pricing error from a fitted term structure, following a spline or parametric form, as in

$$Noise_t^{(U)} = \sqrt{\frac{1}{N_t}\sum_{i=1}^{N_t}\left[y_{i,t} - y_i(b_t)\right]^2},$$

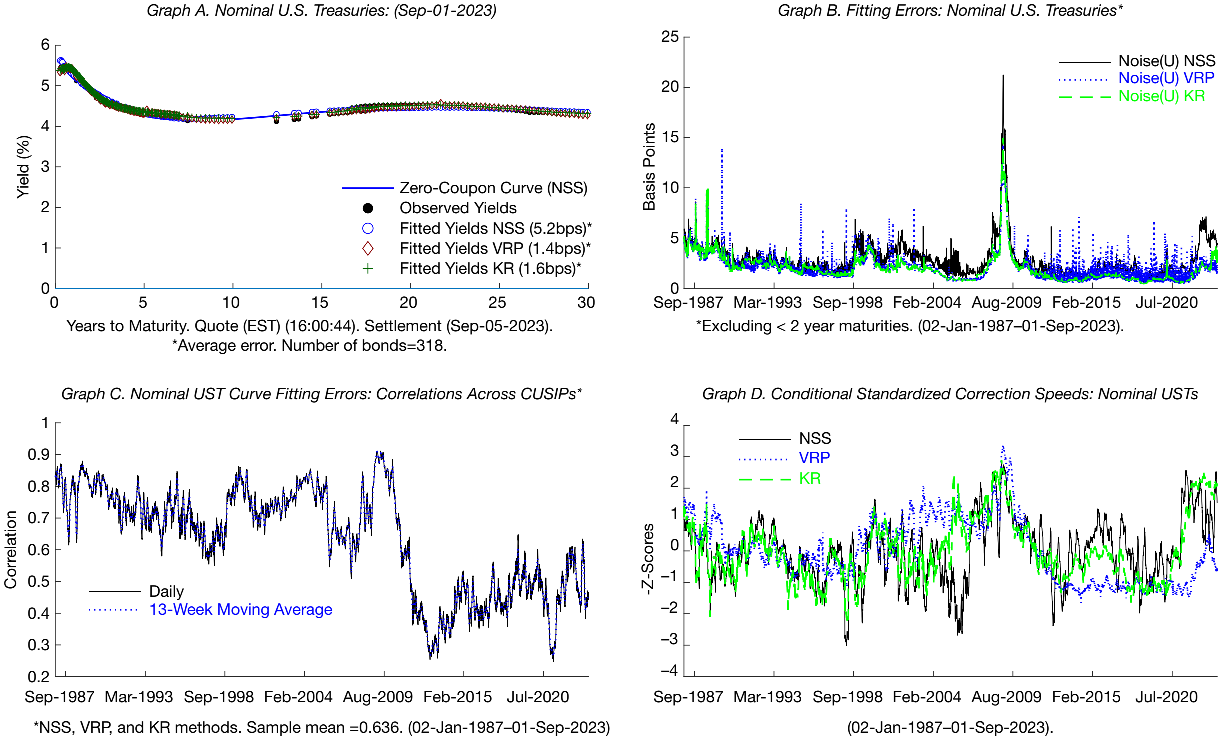
where $y_{i,t}$ is the observed yield at time t on the ith of N UST securities, and $y_i(b_t)$ is the corresponding fitted or predicted value based on the estimated curve at the end of day t given the estimated discount factor, b. $Noise_t^{(U)}$ below empirically departs from HPW by retaining outliers of particular interest among arbitragers and including issues with greater than 10 years to maturity, given that expected bond returns increase with duration, all else equal. Also, this measure excludes CUSIPS of maturities less than 2 years, although the results are substantively similar.

[4] To wit, as Gürkaynak, Sack, and Wright (2007) explain, traders more commonly use splines to uncover anomalies, whereas economists are more interested in the "fundamental determinants of the yield curve" and prefer to smooth through the very variations that may be relevant to frictions.

FIGURE 1

Yield Curve Estimations, Fitting Errors, and Correction Speeds

Graph A of Figure 1 shows NSS, VRP, and KR fitted yields for the last day of the sample, and Graph B shows the time series of the cross-sectional mean fitting errors across these methods, following equation (2). Graph C shows the cross-sectional correlation in errors across all CUSIPs each day. Graph D shows the mean correction speed of conditional pricing errors, following equation (4), for the underlying NSS, VRP, and KR methods, estimated with the 3-month rolling window and expressed in terms of negative *z*-scores.



Graph A. Nominal U.S. Treasuries: (Sep-01-2023)

Years to Maturity. Quote (EST) (16:00:44). Settlement (Sep-05-2023).
*Average error. Number of bonds=318.

*Graph B. Fitting Errors: Nominal U.S. Treasuries**

*Excluding < 2 year maturities. (02-Jan-1987–01-Sep-2023).

*Graph C. Nominal UST Curve Fitting Errors: Correlations Across CUSIPs**

*NSS, VRP, and KR methods. Sample mean =0.636. (02-Jan-1987–01-Sep-2023)

Graph D. Conditional Standardized Correction Speeds: Nominal USTs

(02-Jan-1987–01-Sep-2023).

shows VRP and KR alongside NSS estimates for the last day of the sample, and Graph B shows the time series of the cross-sectional mean fitting errors across methods. Also, the cross-sectional correlation in errors across all CUSIPs each day, shown in Graph C, is clearly less than unity (0.636). The average correlation over the sample varies, too, with a notable decrease toward the end of the sample. As such, the LF stemming from underlying yield curve estimation references NSS- as well as VRP- and KR-based fitting errors.

Second, HPW and subsequent applications strictly report unconditional pricing errors. But following intuition relevant to traders, errors across securities likely owe to seasoning and other factors. To isolate "noise" more precisely, residuals, ε, from cross-sectional regressions comprise conditional pricing error estimates, as in,

$$e_{i,t}^{(U)} = \varphi_0 + \varphi_t{}'\mathbf{X}_t + \varepsilon_{i,t}, \tag{1}$$

where $e_{i,t}^{(U)} = y_{i,t} - y_i(b_t)$ is the unconditional fitting error of bond i based on a given fitting methodology, $\mathbf{X}$ is a vector of proxies for relevant factors,[5] and φ are the factor loadings. The aggregate conditional noise indicator across N_t nominal bonds for any observation t is, therefore,

$$Noise_t^{(C)} = \sqrt{\frac{1}{N_t}\sum_{i=1}^{N_t}\left(e_{i,t}^{(C)}\right)^2}, \tag{2}$$

where $e_{i,t}^{(C)} = \varepsilon_{i,t}$, the conditional fitting error.

Third, as outlined in Durham (2023), the mere size of pricing errors arguably seems secondary to how quickly investors plug arbitrages. Toward a comprehensive liquidity index, it may not just be the size of mean errors but also the speed of error corrections among individual securities that helps capture market functioning. Briefly, $Noise_t^{(U,C)}$ alone misses valuable information about individual securities relevant to capital scarcity.[6] The sticky level of aggregate average noise that HPW report conceivably disguises efficient trading activity. To capture the average error correction speed of curve fitting errors follows time-series regressions for individual CUSIPs,

$$e_{i,t}^{(U,C)} = \alpha + \kappa_i e_{i,t-1}^{(U,C)} + \mu_{i,t}, \tag{3}$$

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[5] $Noise_t^{(C)}$ introduces specification bias. To address this issue, conditional errors refer to weighted averages across alternative specifications of **X** in equation (1). Each model includes bidasked spreads as well as coupon rates. Also, the regressions follow every possible linear combination across two sets of alternative proxies. The first includes three measures related to seasoning, including the ratio of remaining to initial days to maturity and dummies for the first off-the-run or the first- and second-off-the runs. The second set of six variables captures dimensions of free-float supply or central bank intervention, possibly especially relevant given central bank purchases of Treasuries following the GFC. Measures include the fraction of par value across all outstanding securities, net System Open Market Account (SOMA) holdings; the weight of the security as a fraction across all SOMA holdings; as well as dummies for whether the proportion held in SOMA of a given issue is within 95th, 75th, 50th, or 25th percentile.

[6] HPW do report the high persistence of the noise measure for the aggregate market, but they do not distinguish whether errors at the security level are persistent.

where κ captures the speed with which fitting errors of security *i* correct from $t-1$ to *t*, given a rolling window. Simply, $\widehat{\kappa} < 0$ implies that pricing errors indeed correct.[7] The aggregate speed measure is the average estimate across all N_t securities for which data are available, using both NSS and VRP estimates as well as unconditional and conditional errors, as in,

$$\text{(4)} \qquad Speed_t^{(U,C)} = \sqrt{\frac{1}{N_t}\sum_{i=1}^{N_t}\left(1-\widehat{\kappa}_{i,t}\right)}.$$

Graph D of Figure 1 shows the estimates based on conditional pricing errors for underlying NSS-, VRP-, and KR-based estimates, expressed in terms of negative *z*-scores, as higher readings indicate greater illiquidity. The speed measure follows intuition with a peak near the GFC and shows some net worsening toward the end of the sample using each fitting metric.

Fourth, given the three alternative fitting methods, the analyses also exploit the dispersion of estimates and addresses "model risk" (Green and Figlewski (1999)). For example, Graph A of Figure 2 shows the median of *N* standard deviations for each CUSIP across methods, for each day of the sample, based on both conditional and unconditional pricing errors. The underlying notion is that, just as the size and speed of pricing errors may connote a decline in arbitrageurs' willingness to commit capital, so too might greater dispersion of pricing estimates across individual CUSIPs based on alternative curve-fitting methodologies, which in turn traces to model risk. Indeed, although the series is noisier, both appear to peak intuitively around the GFC and increase toward the end of the sample. Moreover, for completeness, another related liquidity measure combines information about the size and standard deviation of unconditional and conditional pricing errors from individual CUSIPS each day. These metrics address the possibility that investors may discount the magnitude of pricing errors, amid greater dispersion of underlying estimates across CUSIPs. Graph B of Figure 2 indicates that these measures are less volatile in general and were also elevated during the GFC, as well as earlier in the sample.

The final variable that contributes to the LF is the on-the-run premium, a common proxy. This measure, shown in Graph C of Figure 2, is the NSS-coefficient-based yield on a synthetic security with the same maturity as the most recently issued 10-year note, minus the observed on-the-run yield. Briefly, the series largely follows intuition, with substantially greater readings amid the GFC, for example. All in all, the LF used in the affine-model estimation is the first principal component (PC1) across all measures. As noted in Table 1, PC1 accounts for about 52% of the total variation in these metrics over the sample. Also, Table 1 shows the daily sample correlation matrix of all components of the LF. As suspected, the measures are largely positively but far from perfectly correlated. Finally, the LF series, shown in Graph D of Figure 2, follows an intuitive pattern, with an obvious peak during the GFC as well as some modest net deterioration toward the end of the sample.[8]

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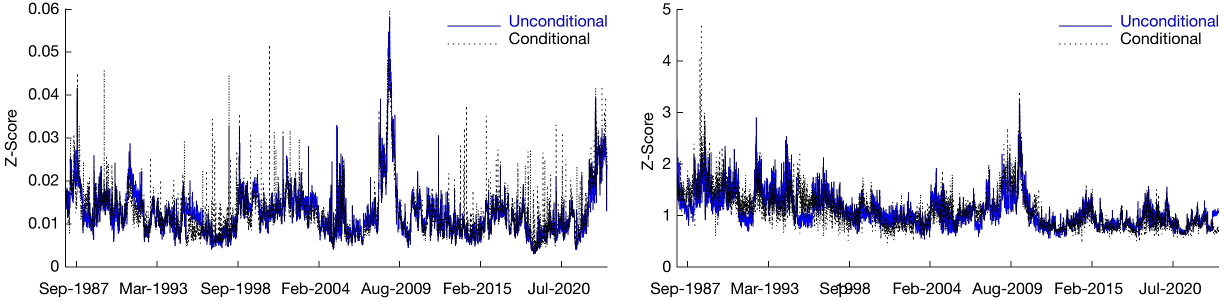
[7] The results refer to a 3-month rolling window, an ultimately arbitrary length.

[8] One possible alternative would be to develop maturity-specific liquidity proxies, in turn, to afford a liquidity-adjusted yield curve, maturity by maturity, to compare alongside a correspondingly "dirty" term structure. As Appendix B of the Supplementary Material details, estimated relations between curve-

FIGURE 2

The Liquidity Factor and Selected Components

Graph A of Figure 2 shows the median of *N* standard deviations of fitting errors for each CUSIP across the NSS, VRP, and KR methods, for each day of the sample, based on both conditional and unconditional pricing errors. Graph B combines information about the size and standard deviation of unconditional and conditional pricing errors from individual CUSIPS each day. Graph C shows the 10-year on-the-run premium based on the NSS methods. Graph D shows the aggregate LF, the first PC of the variables listed in Table 1.

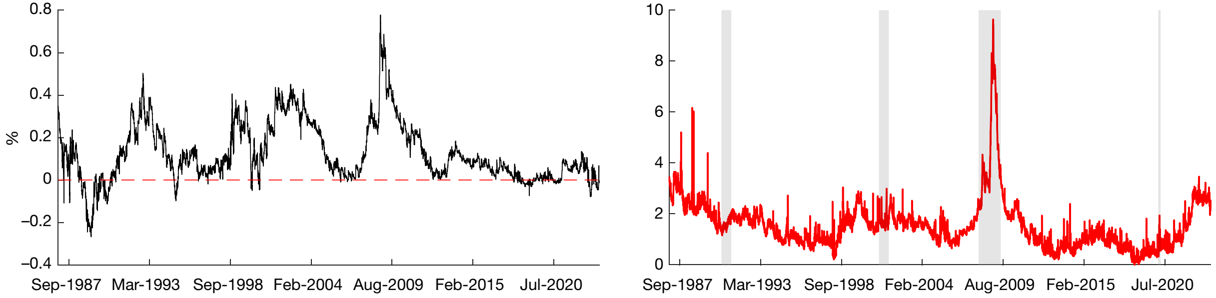


*Graph A. Nominal UST Curve: Median Standard Deviations Across Fitting Methods**

*Graph B. Nominal UST Curve: Mean Noise/Standard Deviations Across Fitting Methods**

*NSS, VRP, and KR methods (02-Jan-1987–01-Sep-2023).

*NSS, VRP, and KR methods (02-Jan-1987–01-Sep-2023).



*Graph C. Nominal 10-Year UST On-the-Run Premium**

Graph D. Nominal U.S. Treasury Liquidity Factor

*Based on NSS (02-Jan-1987–01-Sep-2023).

*(02-Jan-1987–01-Sep-2023).

TABLE 1

Nominal USTs Liquidity Measures: Daily Correlation Matrix

Table 1 shows the correlation matrix of daily observations—from Jan. 2, 1987, to Sept. 1, 2023—on the variables that inform the nominal UST LF. The first principal component accounts for 52% of the variance. Figures in bold in the last row refer to the sample loadings on the first principal component (PC1).

	OTR Premium NSS	Noise(U) NSS	Noise(U) VRP	Noise(U) KR	Noise(C) NSS	Noise(C) VRP	Noise(C) KR	Speed(U) NSS	Speed(U) VRP	Speed (U) KR	Speed(C) NSS	Speed(C) VRP	Speed (C) KR	Std. Dev. (U)	Std. Dev. (C)	Mean Noise(U)/ Std. Dev. (U)	Mean Noise(U)/ Std. Dev. (C)
OTR Premium NSS	1.00																
Noise(U) NSS	0.49	1.00															
Noise(U) VRP	0.45	0.87	1.00														
Noise(U) KR	0.47	0.91	0.94	1.00													
Noise(C) NSS	0.38	0.96	0.84	0.88	1.00												
Noise(C) VRP	0.32	0.78	0.95	0.85	0.79	1.00											
Noise(C) KR	0.33	0.85	0.91	0.94	0.88	0.86	1.00										
Speed(U) NSS	0.24	0.36	0.27	0.29	0.34	0.24	0.22	1.00									
Speed(U) VRP	0.52	0.60	0.56	0.62	0.57	0.46	0.58	0.15	1.00								
Speed(U) KR	0.25	0.43	0.29	0.32	0.45	0.24	0.27	0.61	0.50	1.00							
Speed(C) NSS	0.25	0.40	0.31	0.33	0.39	0.27	0.27	0.96	0.23	0.65	1.00						
Speed(C) VRP	0.50	0.58	0.56	0.62	0.56	0.48	0.59	0.12	0.96	0.45	0.19	1.00					
Speed(C) KR	0.21	0.49	0.32	0.36	0.52	0.27	0.32	0.61	0.55	0.88	0.68	0.49	1.00				
Std. Dev. (U)	0.37	0.86	0.69	0.74	0.86	0.62	0.67	0.31	0.48	0.38	0.34	0.47	0.44	1.00			
Std. Dev. (C)	0.30	0.82	0.69	0.68	0.86	0.70	0.65	0.31	0.43	0.38	0.33	0.41	0.46	0.92	1.00		
Mean Noise(U)/ Std. Dev.(U)	0.11	0.14	0.31	0.34	0.13	0.28	0.39	0.02	0.29	0.00	0.05	0.28	0.01	−0.15	−0.09	1.00	
Mean Noise(U)/ Std. Dev.(C)	0.11	0.22	0.39	0.47	0.25	0.37	0.55	0.01	0.39	0.06	0.06	0.41	0.06	−0.02	−0.08	0.79	1.00
Memo: PC1 Loadings	**0.17**	**0.32**	**0.30**	**0.31**	**0.31**	**0.28**	**0.30**	**0.15**	**0.25**	**0.19**	**0.17**	**0.24**	**0.20**	**0.27**	**0.27**	**0.09**	**0.12**

III. An ATSM of Nominal USTs with Embedded Liquidity Risk

This study proposes no innovations in ATSM formulae, fully detailed in Appendix A of the Supplementary Material. To review the decomposition of yields, aggregate expected excess return on an *n*-period nominal UST security over the anticipated short-rate path, aka the "term premium," at time *t* follows:

$$tp_{n,t} = y_{n,t} - \tilde{y}_{n,t}, \tag{5}$$

where $y_{n,t}$ references the model-fitted yield, and the risk-adjusted yield, $\tilde{y}_{n,t}$, embeds the frictionless average expected nominal short rate over n, $\tilde{y}^f_{n,t}$, as well as the anticipated friction, or the risk-adjusted loading on the LF, $\tilde{l}_{n,t}$, as in,

$$\tilde{y}_{n,t} = \tilde{y}^f_{n,t} + \tilde{l}_{n,t}. \tag{6}$$

Correspondingly, the aggregate term premium, $tp_{n,t}$, includes both the frictionless nominal term premium, $tp^f_{n,t}$, and the liquidity premium, $lp_{n,t}$, as an alternative expression to equation (5),

$$tp_{n,t} = tp^f_{n,t} + lp_{n,t}. \tag{7}$$

To disentangle the quantities in equations (6) and (7), the ATSM embeds liquidity risk as an observable, orthogonal element in among the factors that affect bond yields. To parse further aggregate required excess returns, the frictionless nominal term premium component, follows:

$$tp^f_{n,t} = y^f_{n,t} - \tilde{y}^f_{n,t}. \tag{8}$$

The liquidity premium on an *n*-period nominal security, $lp_{n,t}$, the compensation bond investors demand for liquidity risk, is strictly defined below from equation (7), and with rearranging,

$$\begin{aligned} lp_{n,t} &= tp_{n,t} - tp^f_{n,t} \\ &= (y_{n,t} - \tilde{y}_{n,t}) - (y^f_{n,t} - \tilde{y}^f_{n,t}) \\ &= \underbrace{(y_{n,t} - y^f_{n,t})}_{\text{liquidity loading}} - \underbrace{(\tilde{y}_{n,t} - \tilde{y}^f_{n,t})}_{\text{risk-adjusted liquidity loading}}. \end{aligned} \tag{9}$$

The premium is therefore the difference between the liquidity loading of the bond, that is, the remainder after subtracting the frictionless yield from the overall yield, and its risk-adjusted loading, which approximates expected illiquidity over *n*.[9]

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fitting errors and functional forms of liquidity are weak in these data. But further analysis along these lines seems would boost confidence in the salience of the LF.

[9] As noted in Durham (2023), studies of liquidity premiums in TIPS commonly refer to the first bracketed term, the "liquidity loading," as the "liquidity premium." Under this common definition, the premium includes not only $lp_{n,t}$ but also expected liquidity. This formulation seems inconsistent with common parlance that "premium" refers to the price not the quantity of risk. Similarly, in standard affine

A. Empirical Specification, Factor Construction, Model Estimation, and Overall Fit

The basis of the empirics comprises zero-coupon bond yields estimated from underlying price quotes and other data on individual securities from CRSP.[10] Rather than GSW updates, the yield curve is based on the NSS methodology and fit daily for securities with initial maturities from 3 months to 30 years. The sample for ATSM parameter estimation covers Jan. 1987 to Aug. 2023, for a total of 440 monthly observations, taken at month ends, and the daily series of decompositions runs from Jan. 2, 1987, to Sept. 1, 2023 (9,165 observations).

The set of observable model factors, x, includes the standardized LF, which identifies the key parameters and in turn the frictionless quantities described previously. The remaining factors derive from OLS regressions of yields on the LF, using maturities from 3, 4, …, 119, and 120 months. The first four conditional principal components (PCs) of the time series of residuals across each maturity comprise the remainder of x. As such, the first, second, and third PCs, say, crudely capture the "frictionless" level, slope, and curvature of the nominal term structure.

Graphs A–E of Figure 3 show the sample time series of the first five unconditional PCs of nominal yields (the dotted lines), analogous to the 5-factor ACM model, alongside each element of x (the solid lines). Correlations across the first and fourth conditional and unconditional PCs (PC1 and PC4) are very close to unity, around 0.97 and 0.98, respectively (Graphs A and D), but there are some discrepancies. The correlations for the slope diverge during the GFC (Graph B), with a sharp increase in the unconditional measure but a larger decrease conditioned on the LF. This divergence may informally suggest the spike in yields during the period owed to deteriorating market conditions, rather the higher expected policy rates or term premiums, to be assessed more formally below. Nonetheless, the overall sample correlation across slope factors is 0.97. The correlation across the curvature factors is similarly tight (0.96) (Graph C), and the unconditional PC5 and the LF are effectively uncorrelated (about −0.05), as expected (Graph E).

Given the factors, estimation of the model largely follows the 3-step linear regression procedure outlined in ACM. First, a standard OLS VAR produces the parameters for the factor dynamics. The second and third steps recover the market prices of risk and fitting errors from monthly excess return regressions estimated for 11 maturity points—6, 12, 24, 36, 48, 60, 72, 84, 96, 108, and 120 months—where excess returns over 1-month rates are a function of contemporaneous factor innovations and lagged values of the factors.

Table 2 summarizes the close fits of the return regressions for each maturity over the full sample. The R^2 values are very close to unity for maturities beyond a

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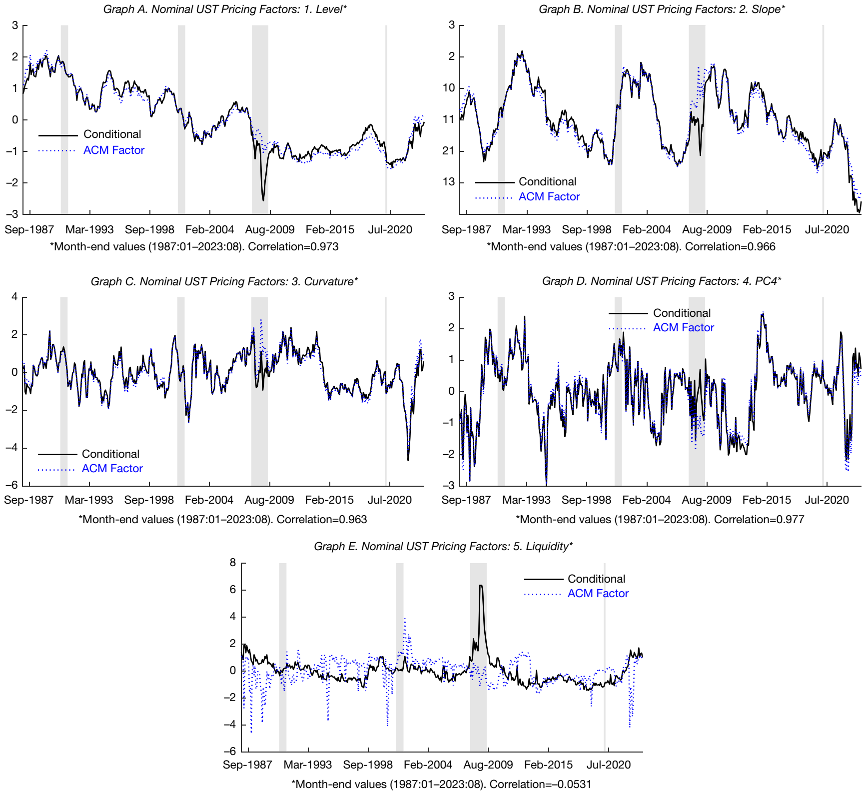
models of nominal securities, the "term premium" by construction excludes the expected-rate component of yields. Therefore, equation (9), again embedded within required excess return following equation (7), does not include any component of "expected liquidity risk," and $lp_{n,t}$ captures the compensation for bearing illiquidity, not the quantity.

[10] See CRSP (2010) and updates for descriptions of the security-level data set. Estimates beyond 2020 use Bloomberg quotes.

FIGURE 3

The Liquidity and Frictionless Yield Curve Factors

The solid lines in Graphs A–E of Figure 3 show the underlying factors in the ATSM, alongside the corresponding first five unconditional principal components of the cross section of nominal UST yields (dotted lines), measured monthly.



*Graph A. Nominal UST Pricing Factors: 1. Level**

*Month-end values (1987:01–2023:08). Correlation=0.973

*Graph B. Nominal UST Pricing Factors: 2. Slope**

*Month-end values (1987:01–2023:08). Correlation=0.966

*Graph C. Nominal UST Pricing Factors: 3. Curvature**

*Month-end values (1987:01–2023:08). Correlation=0.963

*Graph D. Nominal UST Pricing Factors: 4. PC4**

*Month-end values (1987:01–2023:08). Correlation=0.977

*Graph E. Nominal UST Pricing Factors: 5. Liquidity**

*Month-end values (1987:01–2023:08). Correlation=–0.0531

TABLE 2

Model Diagnostics: Nominal USTs Return Pricing Errors

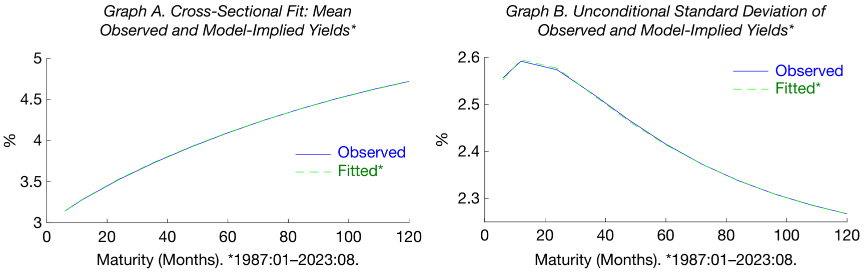
Table 2 summarizes the fits of the monthly excess return regressions (following ACM) used in the model estimation. The monthly sample for returns runs from Feb. 1987 to Aug. 2023 (439 observations).

Maturity (Months):	Mean	Std. Dev.	Skewness	Kurtosis	R^2
6	0.0000	0.0002	0.9964	12.4781	0.9553
12	0.0000	0.0002	1.0529	9.1123	0.9874
24	0.0000	0.0001	0.8853	12.9217	0.9993
36	0.0000	0.0003	0.4048	7.2822	0.9990
48	0.0000	0.0002	0.0580	6.0054	0.9997
60	0.0000	0.0003	0.9669	8.8629	0.9995
72	0.0000	0.0005	0.4669	7.1689	0.9991
84	0.0000	0.0005	0.3283	6.4670	0.9993
96	0.0000	0.0003	0.5949	6.8977	0.9999
108	0.0000	0.0003	0.1821	7.8130	0.9998
120	0.0000	0.0011	0.0914	6.5612	0.9983

FIGURE 4

Model-Implied Yields: The Cross Section

Graph A of Figure 4 shows the full-sample average actual and fitted values across maturities from 6 months to 10 years, and Graph B illustrates the corresponding average unconditional standard deviations of observed and fitted values.



year, with the lowest reading of about 0.955 at the 6-month horizon, and the mean errors are extremely close to zero, with very small standard deviations. The residuals do not appear to skew in either direction consistently, although kurtosis estimates are larger than Gaussian distributions imply. Yet on balance, the excess return regressions imply a very close fit to nominal yields.

Furthermore, Graph A of Figure 4 shows the full-sample average actual and fitted values across the range of maturities, and Graph B illustrates the corresponding average unconditional standard deviations of observed and fitted values. Taken together, both charts suggest that the specification matches the first and second moments very closely. Moreover, Graphs A–K of Figure 5 show the monthly time series of errors from the 6- to the 120-month maturities over the sample, and Panel A of Table 3 lists summary statistics for the fitted values of yields for each maturity, which correspond closely to the actual figures, within a couple basis points (bps).[11] To be precise, as noted in the second column, the root mean squared errors (RMSEs) range from about 0.53 to 1.69 bps at the 60- and 12-month maturities, respectively. These pricing errors are within the magnitudes of corresponding figures in several other studies. The standard deviations, the third column, are also small, between 0.66 and 2.17 bps, and the skewness and kurtosis of the pricing errors are also within the range of similar estimates reported in previous studies. Like several applications of ATSM calibrated to fit yields, corresponding pricing errors are typically larger for forward rates. As Panel B of Table 3 indicates, RMSEs range from about 2.40 to 13.58 bps at the 12- and 120-month horizons, respectively.

B. The Liquidity Loadings

To underscore the merits of including a LF in an ATSM of nominal yields, Graph A of Figure 6 shows the yield loadings on each of the factors by maturity, which can be interpreted as the n-month yield response to contemporaneous

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[11] As a departure from ACM, further estimation uses the market price of risk parameters from steps 2 and 3 as starting values in a standard MLE-based minimization of yield pricing errors.

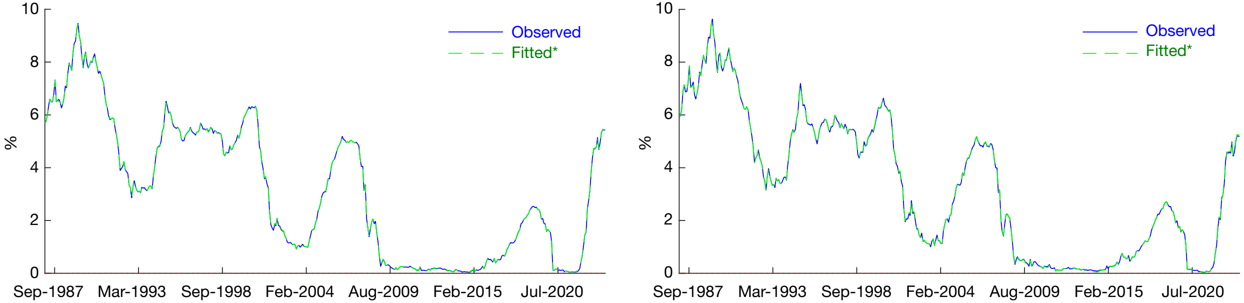
FIGURE 5

Model Implied Yields: Time Series

Graphs A–K of Figure 5 are time series plots of observed (the solid lines) and model implied (dashed) nominal UST yields at a monthly frequency over the sample.

*Graph A. Zero-Coupon Yields: Nominal USTs: 6M**

*Graph B. Zero-Coupon Yields: Nominal USTs: 12M**

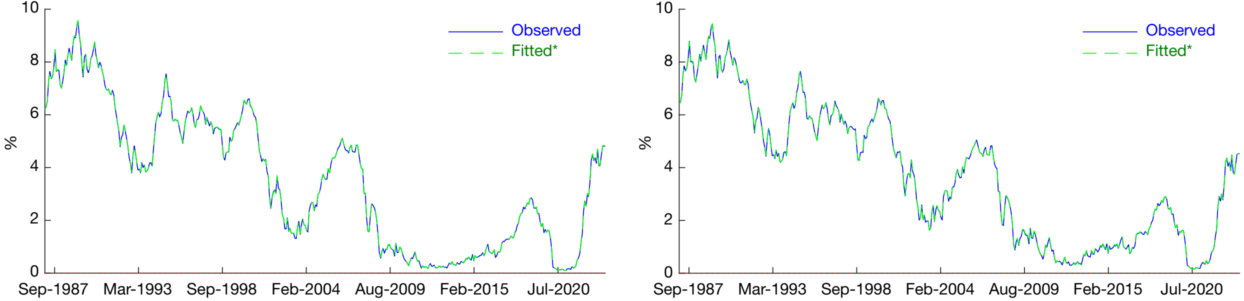


Mean squared fitting error =1.06bps. (1987:01–2023:08).

Mean squared fitting error =1.69bps. (1987:01–2023:08).

*Graph C. Zero-Coupon Yields: Nominal USTs: 24M**

*Graph D. Zero-Coupon Yields: Nominal USTs: 36M**

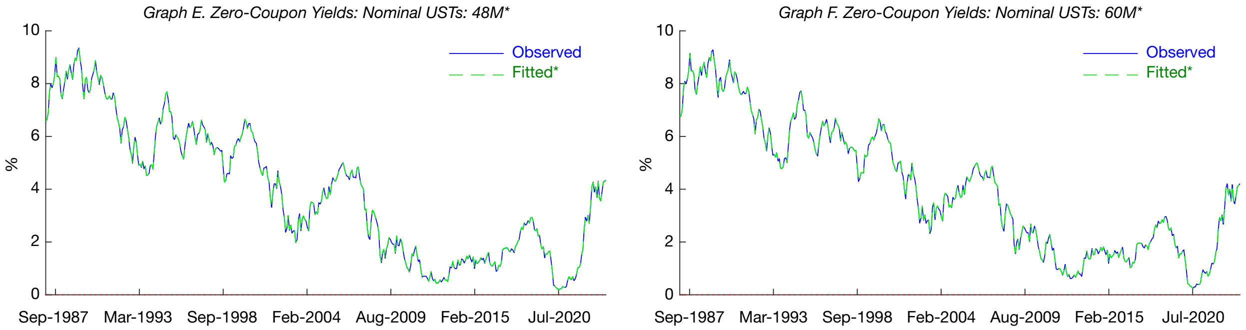


Mean squared fitting error =0.893bps. (1987:01–2023:08).

Mean squared fitting error =1.21bps. (1987:01–2023:08).

FIGURE 5 (continued)

Model Implied Yields: Time Series

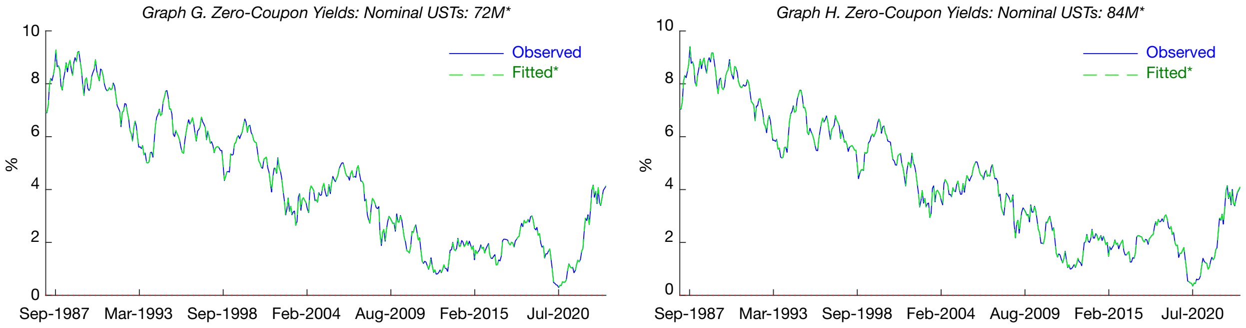


*Graph E. Zero-Coupon Yields: Nominal USTs: 48M**

Mean squared fitting error =0.809bps. (1987:01–2023:08).

*Graph F. Zero-Coupon Yields: Nominal USTs: 60M**

Mean squared fitting error =0.533bps. (1987:01–2023:08).



*Graph G. Zero-Coupon Yields: Nominal USTs: 72M**

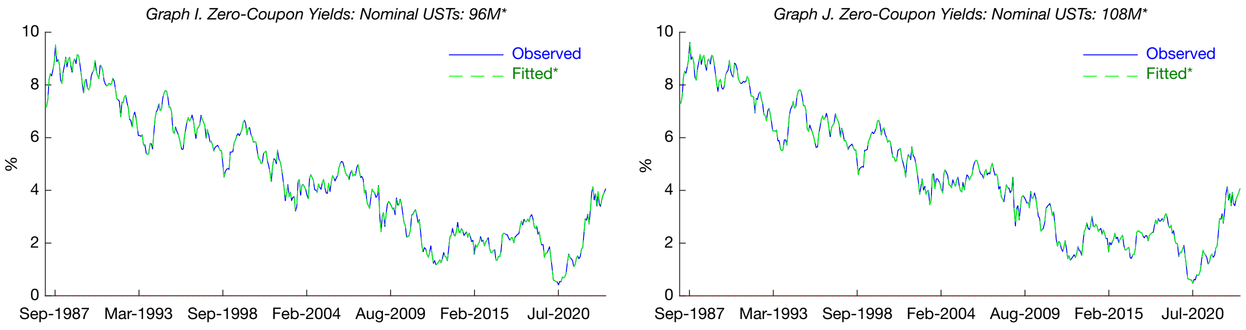
Mean squared fitting error =0.83bps. (1987:01–2023:08).

*Graph H. Zero-Coupon Yields: Nominal USTs: 84M**

Mean squared fitting error =0.861bps. (1987:01–2023:08).

FIGURE 5 (continued)

Model Implied Yields: Time Series

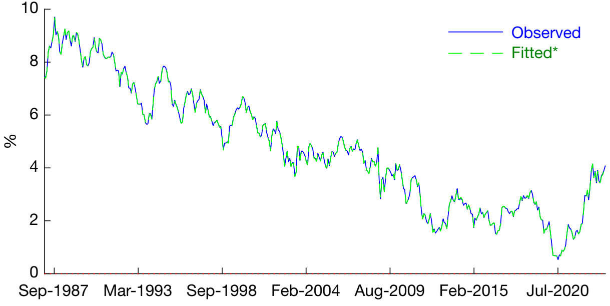


*Graph I. Zero-Coupon Yields: Nominal USTs: 96M**

Mean squared fitting error =0.62bps. (1987:01–2023:08).

*Graph J. Zero-Coupon Yields: Nominal USTs: 108M**

Mean squared fitting error =0.621bps. (1987:01–2023:08).



*Graph K. Zero-Coupon Yields: Nominal USTs: 120M**

Mean squared fitting error =1.48bps. (1987:01–2023:08).

TABLE 3

Model Diagnostics: Nominal UST Yield and (1-Month) Forward Rate Pricing Errors

Panel A of Table 3 summarizes diagnostics of the fit of the ATSM to nominal UST yields and corresponds with the time series from Figure 5. Panel B of Table 3 includes the corresponding information for one-month forward rates. The monthly sample for yields and forward rates runs from Jan. 1987 to Aug. 2023 (440 observations).

Panel A. Yields					*Panel B. Forward Rates*				
Maturity (Months)	RSME (BPS)	Std. Dev. (BPS)	Skewness	Kurtosis	Maturity (Months):	RSME (BPS)	Std. Dev. (BPS)	Skewness	Kurtosis
6	1.06	1.56	0.11	8.51	6	4.93	7.15	0.81	9.80
12	1.69	2.17	0.43	5.31	12	2.40	2.92	0.20	4.46
24	0.89	1.08	−0.86	7.81	24	3.90	4.85	−0.55	3.30
36	1.21	1.41	−0.36	2.51	36	2.44	3.63	−1.60	8.11
48	0.81	0.94	−0.63	3.10	48	3.33	4.43	0.00	4.46
60	0.53	0.66	0.47	7.39	60	4.49	5.62	0.26	3.21
72	0.83	0.99	0.42	3.00	72	3.96	5.12	0.41	3.86
84	0.86	1.08	0.30	2.87	84	3.27	4.27	0.00	4.06
96	0.62	0.77	0.28	3.40	96	5.24	6.43	−0.51	3.75
108	0.62	0.71	−0.33	3.28	108	9.03	11.02	−0.36	2.95
120	1.48	1.74	−0.31	2.66	120	13.58	17.46	−0.19	3.50

standardized shocks. These estimates reinforce the ubiquitous interpretation of the level, slope, and curvature factors in the literature, although conditioned on the LF, and the loadings on PC3 and PC4 are very modest.

More to the point, the average absolute magnitude of the responses to liquidity shocks across all maturities is substantial, about 0.552 in absolute value (and percentage-point yield terms) as noted in Graph F of Figure 6, albeit not as large a sensitivity as the level of the term structure (2.327, Graph B), but easily at least as sizeable across maturities in absolute value as the slope (0.324, Graph C). Moreover, the sensitivity to liquidity is meaningful across tenors and increases out the term structure. Also, the dotted lines Graphs B–F show corresponding OLS loadings, based on simple regressions of observed yields on the model factors. All estimates are quite close to the arbitrage-free yield loadings and follow similar patterns across maturities, with clearly no diminution in the estimates for the LF given this alternative tack.

Further robustness checks to this factor construction, detailed in Appendix C of the Supplementary Material, imply meaningful liquidity effects on nominal yields. The coefficients on the LF in the excess return regressions are also second in magnitude only to the level, the nominal liquidity loadings are comparable in magnitude to corresponding estimates for TIPS, and reduced-form regressions suggest strong liquidity effects, controlling for macroeconomic as well as other variables and with no assumptions about the factor structure or the orthogonalization.

C. Nominal Yield Decompositions

The model diagnostics boost confidence in its implied decompositions of yields, including parsing the required return component further into the frictionless term and liquidity premiums. Graph A of Figure 7 shows the unconditional average fitted term structure from 5 to 10 years over the full sample (the dotted black line),

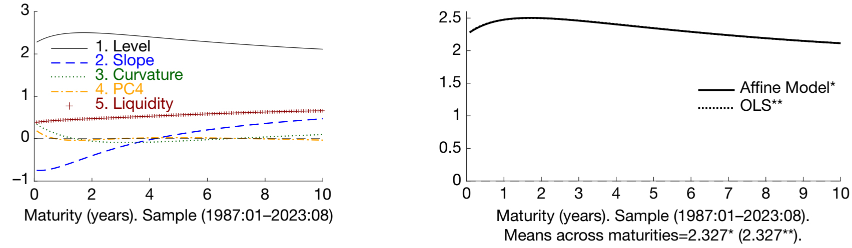
FIGURE 6

Yield Factor Loadings

Graph A of Figure 6 shows the ATSM-implied yield loadings on each factor, the *n*-month yield response to contemporaneous standardized shocks. The solid lines in Graphs B–F show the same estimates, factor by factor, alongside the corresponding OLS-based loadings (the dotted lines) derived from regressing nominal UST yields at each maturity on the factors.

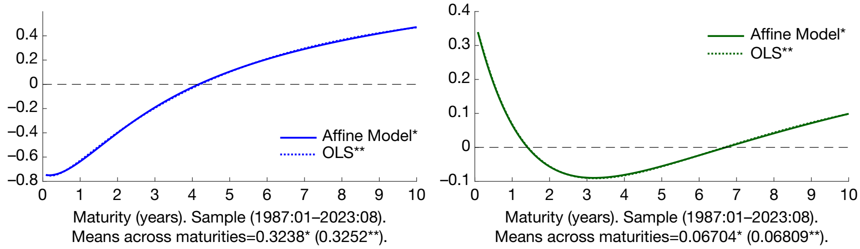
Graph A. Affine Model Yield Loadings: Nominal USTs

*Graph B. Yield Loadings: Nominal USTs: 1. Level**



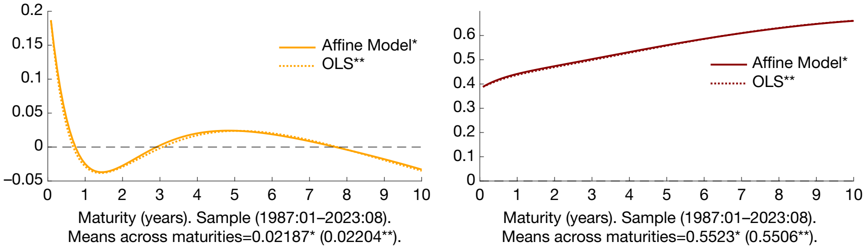
*Graph C. Yield Loadings: Nominal USTs: 2. Slope**

*Graph D. Yield Loadings: Nominal USTs: 3. Curvature**



*Graph E. Yield Loadings: Nominal USTs: 4. PC4**

*Graph F. Yield Loadings: Nominal USTs: 5. Liquidity**



including anticipated average expected rates through each maturity (dashed green) as well as frictionless term premiums (solid blue). The flat mean anticipated nominal short rate path across tenors, at around 3% over the full sample, contradicts the strong-form expectations hypothesis (Gürkaynak and Wright (2012)), insofar as the observed average upward slope to the observed curve owes entirely to estimated positive frictionless term premiums.

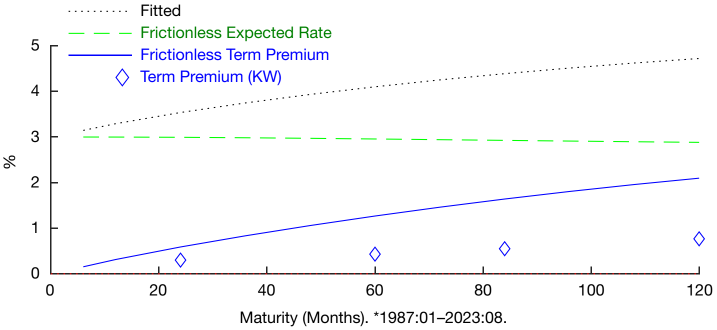
Furthermore, as listed in Table 4, based on all available overlapping data from alternative ATSMs, on average the nominal liquidity premium is about −31 bps on average. However, the central tendency disguises meaningful variation, given a standard deviation of about 44 bps and a range from −96 to 335 bps. Indeed, the finer decomposition affords notable alternative interpretations arguably at key junctures in the sample. To start, Graph B of Figure 7 shows the times-

FIGURE 7

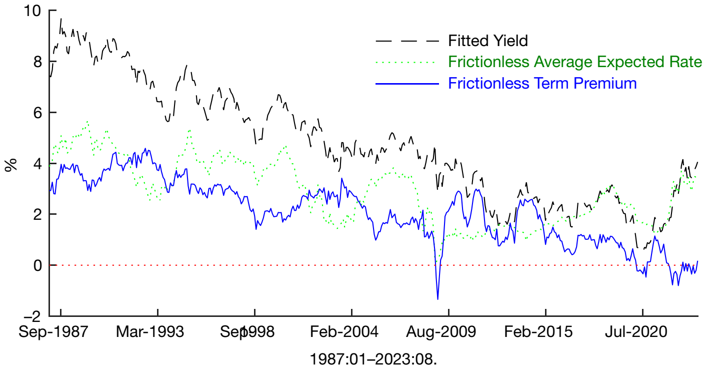
Model Decomposition of Yields: Frictionless Term and Liquidity Premiums

Graph A of Figure 7 shows the average fitted values, frictionless average expected rates, and frictionless term premiums for maturities through 10 years over the monthly sample. Graph B shows the implied decomposition of 10-year nominal yields, including frictionless average expected rates and term premiums, monthly over the same period. Graph C shows the 10-year frictionless term and liquidity premiums based on the model, alongside KW and ACM term premium estimates, daily from Jan. 2, 1990.

*Graph A. Unconditional Mean Nominal UST Zero-Coupon Decomposition**



*Graph B. 10Y Nominal Treasury Decomposition**



*Graph C. 10-Year Term and Liquidity Premiums: Nominal USTs**

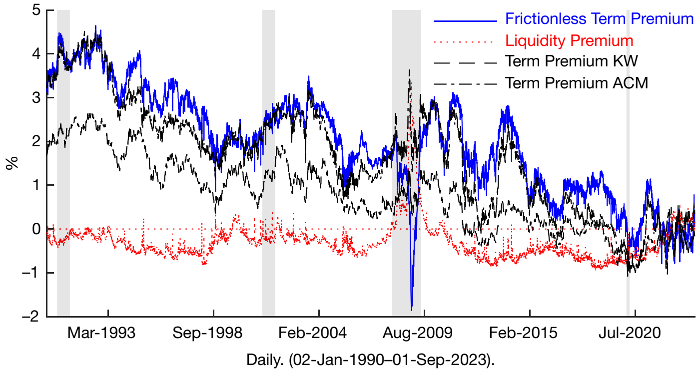


TABLE 4

Nominal UST ATSM Selected Decompositions: 10-Year Zero-Coupon Yields

Table 4 summarizes the series of decompositions of nominal USTs shown in Figures 7 and 8 for all available data from Jan. 2, 1990, when the KW estimates become available, to Sept. 1, 2023.

Component	Mean (%)	Std. Dev. (%)	Minimum (%)	Maximum (%)
Liquidity premium	−0.31	0.44	−0.96	3.35
Liquidity risk-neutral loading	−0.01	0.10	−0.15	0.80
Frictionless term premium	1.97	1.21	−1.86	4.64
Term premium KW	0.77	0.85	−0.95	2.71
Term premium ACM	1.68	1.26	−1.13	4.62
Frictionless average expected rate	2.72	1.18	−0.22	5.50
Average expected rate KW	3.65	1.28	1.54	6.75
Average expected rate ACM	2.72	1.18	0.84	5.54

series decomposition of 10-year nominal yields (the dashed black line), again into average expected rates (dotted green) and frictionless term premiums (solid blue). Visual inspection broadly accords with the widespread narrative that both components of yields have secularly declined. Graph C puts these results into context with estimates from KW and ACM, at the same horizon. The frictionless term premium correlates about as closely overall with both alternatives, given a 0.90 (0.91) correlation with KW (ACM) as listed in Table 5. Also, returning to Table 4, the net sample average decomposition between short rates (2.72% vs. 2.72%) is naturally similar across this model and ACM, but the frictionless component of required returns is greater on average than the ACM term premiums (1.97% vs. 1.68%). Also, the KW model produces greater anticipated average short rates (3.65%) and lower average term premiums (0.77%) at the 10-year horizon.

However, Graph C of Figure 7 also shows a notable divergence during the GFC, with a precipitous drop in the frictionless term premium into negative territory during the period. By sharp contrast, the ACM and KW term premium estimates are elevated and especially highly correlated during this outlying episode with the estimated nominal liquidity premium, which hits its daily sample peak around height of the crisis. Interestingly, and discussed later in terms of cyclicality, the sample correlations between the liquidity premium and corresponding estimates from KW and ACM are about 0.25 and 0.30, respectively, compared to −0.11 with the frictionless term premium. At first blush, therefore, courser term premium estimates may also embed meaningful information about liquidity risks, particularly at extremes when model decompositions are of keenest interest.

Turning to comovement in model-implied expected rates, Graph A of Figure 8 shows the mean anticipated short rate over 10 years on the frictionless basis (solid green), compared to the measures from KW (dashed black) and ACM (dotted black). Clearly, the series are very highly correlated, as the coefficients between the frictionless measure and KW and ACM are 0.89 and 0.97, as listed in Table 5. Also, at the furthest horizon, anticipated 1-month and 1-year anticipated rates based on the frictionless measure and KW, respectively, remain tightly correlated, at 0.80, as Graph B of Figure 8 shows. Finally, Graph C shows the trajectory of anticipated 1-month frictionless expected rates for the last sample observation (solid green

TABLE 5

Nominal 10-Year Zero-Coupon Yield Decompositions Across Selected ATSMs: Correlations

Table 5 summarizes correlations given all available overlapping daily data across key frictionless nominal decompositions as well as KW and ACM as alternative estimates, from Jan. 2, 1990, to Sept. 1, 2023.

	Liquidity Premium	Liquidity Risk-Neutral Loading	Frictionless Term Premium	Term Premium KW	Term Premium ACM	Frictionless Average Expected Rate	Average Expected Rate KW	Average Expected Rate ACM
Liquidity premium	1.00							
Liquidity risk-neutral loading	1.00	1.00						
Frictionless term premium	−0.11	−0.11	1.00					
Term premium KW	0.24	0.24	0.90	1.00				
Term premium ACM	0.29	0.29	0.91	0.95	1.00			
Frictionless average expected rate	−0.14	−0.14	0.43	0.53	0.36	1.00		
Average expected rate KW	0.12	0.12	0.69	0.79	0.70	0.89	1.00	
Average expected rate ACM	0.00	0.00	0.42	0.56	0.38	0.97	0.91	1.00

line), alongside the corresponding forward term structures for the frictionless term premium (dotted blue) and the liquidity premium (dashed red). The estimates suggest anticipated monetary policy easing over the subsequent 2 years, with a gradual reduction in rates that asymptotes toward a longer-run equilibrium nominal rate.

IV. Empirical Applications

This section considers further applications. The first regards the cyclicality of liquidity and frictionless term premiums. The second reassess the effects of Federal Reserve asset purchases. The third considers a further decomposition of yields with a similar assessment of TIPS and focuses on market-implied expected inflation.

A. Premia Cyclicality

Whether term premium estimates are countercyclical—namely, higher during recessions—is a routine validating yardstick for ATSMs.[12] Yet the issue seems far more ambiguous than the literature lets on. Setting aside liquidity, conceivably bond premia cyclicality depends heavily on whether demand or supply shocks primarily buffet the economy, and any evidence of countercyclicality is consistent with the latter. Only under the assumptions that inflation risk dominates nominal bond excess returns and that inflation and growth are negatively correlated, are USTs bad hedges that sell off when consumption deteriorates.[13] Positive

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[12] For example, Bauer, Rudebusch, and Wu (2014) endorse their “bias-corrected” estimates over those of Wright (2011 and 2014) given the reported greater countercyclicality of their measure.

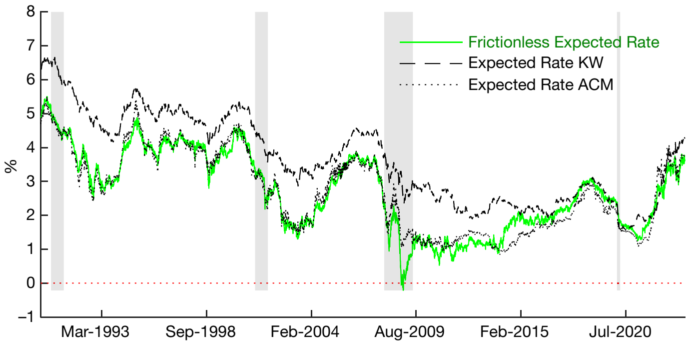
[13] This reasoning largely follows Piazzesi and Schneider (2007) and would help explain positively sloped nominal term structures, as does the model in Wachter (2006).

FIGURE 8

Model Decomposition of Yields: Frictionless Expected Short Rates

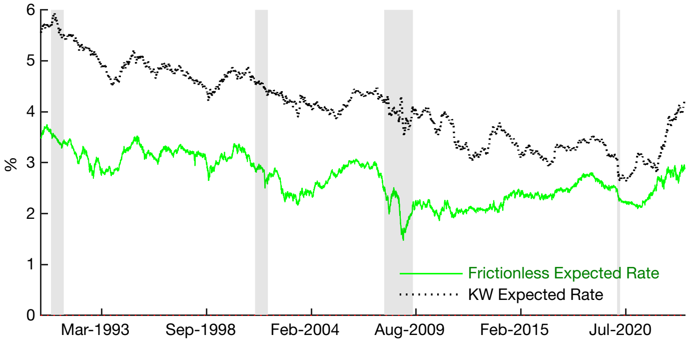
Graph A of Figure 8 shows the mean frictionless anticipated short rate over 10 years (solid green line) and compared to KW (dashed black) and ACM (dotted black). Graph B shows distant-horizon frictionless anticipated rates (solid green line), along with a comparable KW series (dotted black). Graph C shows the trajectory of anticipated 1-month frictionless expected rates for the last sample observation (solid green), alongside the corresponding forward term structures for the frictionless term premium (dotted blue) and the liquidity premium (dashed red).

*Graph A. 10-Year Average Expected Short Rates: Nominal USTs**



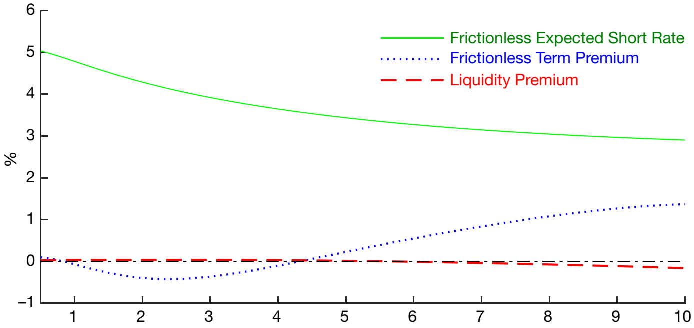
Daily. (02-Jan-1990–01-Sep-2023).

*Graph B. Distant-Forward Expected Short Rates: Nominal USTs**



Daily. (02-Jan-1990–01-Sep-2023) Correlation=0.8.

Graph C. Forward Rate Term Structure (September-01-2023)*



Years. *1-month forwards.

unconditional average term premiums reported previously, “frictionless” or otherwise, is consistent with this story, given this sample overall. Still, in conditional terms over an extended period, (expected) cyclical downturns may not tidily correspond with supply shocks, but rather at other times demand disturbances indicative of a positive expected correlation between inflation and growth. Under these alternatives, the insurance value of nominal USTs augurs for lower if not negative risk premia, as government bonds pay in bad states. Aptly, again as Graph C of Figure 7 illustrates, the frictionless term premium estimate is deeply negative during the GFC, scarcely a supply shock.

As far as cyclicality of liquidity premia, nominal UST losses that owe to deteriorating trading conditions are likely poorly timed. An absolute deterioration in UST liquidity seems more rather than less likely to coincide with worsening trading conditions in other assets, even if all the while the nominal UST market remains comparably the most liquid. Ergo, all else equal, UST liquidity premia are probably greater strictly in absolute terms during “bad times” and thereby countercyclical.

As such, evidence reported in the literature of gross nominal term premium countercyclicality may belie countercyclical liquidity premiums instead. Also, stripped of attitudes toward liquidity risk, the ambiguous cyclicality of frictionless term premiums, contingent on varying perceptions of supply and demand shocks that effect UST hedging value, may become more transparent.[14] To explore cyclicality, time-series regressions of the components of required returns on nominal bonds—frictionless term and liquidity premia—as well as of KW and ACM term premium estimates, $tp_{10Y,t}^{KW}$ and $tp_{10Y,t}^{ACM}$, respectively, on a set of macroeconomic variables, x, that proxy business cycle conditions as well as uncertainty around forecasts, follow:

$$\begin{bmatrix} tp_{10Y,t}^{KW} \\ tp_{10Y,t}^{ACM} \\ tp_{10Y,t}^{f} \\ lp_{10Y,t} \end{bmatrix} = \alpha + \beta' x_t + \varepsilon_t, \tag{10}$$

where x comprises a dummy variable for NBER-defined recessions, as well as the dispersion of 1-year-ahead real GDP and inflation forecasts from Consensus Economics.[15]

Table 6 summarizes the results using all available data from Jan. 1990 to Aug. 2023.[16] Starting with the standard ATSMs in the first two columns, the coefficients on the 10-year KW and ACM estimates are statistically insignificant, and the R^2

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[14] Also, as Bauer et al. (2014) note, flight-to-quality flows at times of market stress connote pro- rather than counter-cyclical term premiums, which may be difficult to otherwise distinguish from liquidity premiums, although both liquidity and risk appetite shocks characterize these episodes.

[15] This specification is consistent with the quarterly panel regressions in Wright (2011) and Bauer et al. (2014).

[16] The left-hand-side variables are sampled from days during a given month when the surveys were taken, not published.

TABLE 6

Decompositions Across ATSMs: Premia Cyclicality

Table 6 summarizes the monthly results for time-series regressions following equation (10) from Jan. 1990 to Aug. 2023. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% confidence levels, based on Newey–West standard errors. The figures in bold denote the results for the proposed model.

	Term Premium KW	Term Premium ACM	Frictionless Term Premium	Liquidity Premium
Intercept	0.744***	1.62***	**1.96*** **	−**0.352*** **
Inflation survey dispersion	0.0199	0.0327	−**0.215**	**0.237*** **
Growth survey dispersion	−0.0191	−0.00985	−**0.0104**	−**0.00939**
NBER recession dummy	0.312	0.708	**0.178**	**0.423** **
R^2	0.0132	0.0315	**0.0282**	**0.455**
No. of obs.	404	404	**404**	**404**

values are rather low. Turning to the results for this framework in the last two columns, the coefficient on the recession dummy for the frictionless term premium is small and insignificant, and the R^2 is about 0.03. However, the last column shows that on average estimated liquidity premiums are about 42 bps greater during recessions, all else equal, and the result is significant at the 5-percent level, with a corresponding R^2 of 0.46.

Therefore, the only robust result on the cyclicality of required returns traces to liquidity risk. Naturally, a reasonable suspicion is that the spike during the GFC primarily produces these results. But as Appendix D of the Supplementary Material details, liquidity premium countercyclicality appears robust to structural breaks in equation (10), band-spectrum regressions that isolate longer-run relations using (continuous) real GDP growth rather than recession indicators, and M-GARCH models that suggest a consistently positive (somewhat ambiguous) correlation between stock returns and the component of required excess bond returns that owes to increases in liquidity (frictionless term) premiums. Moreover, these results reinforce the ambiguous cyclicality of frictionless term premiums and decreasing (increasing) perceptions of supply (demand) shocks over this sample.

A puzzle, which may highlight some inherent limits of this class of ATSMs, lingers. Conditional liquidity premia countercyclicality implies that USTs are risky over the business cycle. But, as reported previously, the unconditional liquidity premium is negative (−31 bps), on balance amid a wide range of estimates. The literature stemming from Krishnamurthy and Vissing-Jorgensen (2012) (KVJ) on "convenience yields," which if anything is consistent with negative unconditional premiums, may be informative on this score.[17] True, their conceptualization of liquidity, and safety too for that matter, is comparative rather than absolute.[18] These estimates by contrast, given that only information from nominal USTs informs the calculations, are absolute rather than relative measures of the liquidity (and the

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[17] By stripping out liquidity loadings and the corresponding premium embedded in nominal yields, these decompositions afford a rare estimate of the quantity that KVJ endorse in their conclusions, namely a frictionless anticipated short rate, with asset-pricing implications.

[18] For example, KVJ strictly address the response of spreads to changes in Treasury supply, among assets that are similar in "safety" (liquidity) but different in liquidity ("safety") to gauge liquidity (safety) premiums.

frictionless term) premium(s).[19] Therefore, at first blush, these estimates are neither consistent nor inconsistent with KVJ, strictly.

Yet, insofar as, say, the spike of the liquidity premium well into positive territory during the financial crisis is simultaneously accompanied by similar if not more pronounced increases in the liquidity premiums of other (risky) assets, then these results hardly conflict with the KVJ, or very low absolute unconditional premia in theory.[20] A judicious assessment of liquidity premiums across risky asset classes is beyond the scope of ATSMs narrowly estimated from government bond data. Not to gainsay inconsistency between unconditional and conditional countercyclical premiums. But absolute liquidity premia countercyclicality does not necessarily imply the same for the relative terms that also matter for wider hedging and asset allocation. Unconditional strong bids for relative nominal UST liquidity seems a reasonable prior, nonetheless.

B. The Effects of LSAPs on Nominal Yield Components

The empirical delineation between frictionless term and liquidity premiums also affords a renewed and finer examination of the effects of Federal Reserve LSAPs. Previous studies in this literature have focused on broad channels, including "portfolio rebalancing" and "signaling," that empirically manifest only through gross term premiums and the anticipated short-rate path. However, at times, central bankers further distinguish between affecting reductions in risk premia through LSAPs, on the one hand, and improving bond market functioning (i.e., "liquidity," on the other). As a key example, the Mar. 15, 2020 FOMC intermeeting statement characterized new purchases in terms of the latter objective—that is, "(t)o support the smooth functioning of markets for Treasury securities"—distinct from the former, at least during the early response to COVID-19.[21] Also, more generally, the mere magnitude of LSAPs, either in terms of its "stock" or "flow," may have somewhat ambiguous liquidity effects, ultimately. Like the Federal Reserve's initial pandemic response, and the Bank of England's temporary intervention in the Gilt market in the fall of 2022 (see Pinter (2023)), purchases may presumably boost market liquidity, up to a point. At another extreme, the Bank of Japan's (BOJ) recent yield curve control policy hardly improves Japanese government bond (JGB) market functioning, strictly.[22] In either case, the ubiquitous courser decompositions

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[19] The same assessment also applies to antecedent estimates of the aggregate term premium in studies from KW to ACM. An apt analogy is that required returns on the yardstick risk-free asset, aka term premiums, might be elevated in absolute but not in relative terms vis-à-vis risky assets.

[20] Moreover, the primary results from KVJ refer to time-series regressions from 1926 to 2008, and therefore their coefficients are static over the sample. Naturally, in contrast, these affine models afford time-varying, daily estimates of all components of nominal yields.

[21] The FOMC began to expand on its rationale as soon as the Apr. 28–29, 2020 meeting, by suggesting that improved liquidity conditions would foster "effective transmission of monetary policy to broader financial conditions." By the Dec. 15–16, 2022 FOMC meeting, the statement more directly acknowledged an additional "credit easing" channel, as the revised language read, "(t)hese asset purchases help foster smooth market functioning and accommodative financial conditions."

[22] Near the time of writing, the BOJ on average owned more than 80% of 10-year JGBs (IMF (2023)), and some individual JGBs reportedly traded only rarely—circumstances that hardly connote that purchases afford "smooth market functioning."

cannot address these subtleties, without the distinction between frictionless term and liquidity premiums.

One common approach to assess LSAP effects is to conduct event studies around subjectively selected announcements. Cumulative changes of yield components—to date, only expected rates and gross term premiums—around policy announcements approximate the general impact of LSAPs. Table 7 updates and expands this tack, but naturally with the proposed finer decompositions, following the initial use of daily responses as in Gagnon et al. (2011),[23] for 25 key dates that span Nov. 25, 2008, to Mar. 23, 2020, referenced across six studies.[24] As noted in the last row, "Total (cumulative sum of selected days)," the cumulative effect based on this simple methodology is notably larger for frictionless term premiums, considering the estimated 97-basis-point decline, than for liquidity premiums, which increased on net by about 9 bps. Also, the cumulative decline in the estimated expected short rate was about 71 bps, consistent with a signaling channel, too. Although the crudest general inference is that asset purchases do not affect liquidity premiums, the estimates for the Mar. 15, 2020 intermeeting (Sunday) FOMC decision nonetheless follows intuition and the stated rationale of the Committee to address market functioning; the estimated liquidity premium dropped 16 bps, whereas the frictionless term premium was unchanged.[25] Further robustness checks, detailed in Appendix E of the Supplementary Material (including assessment of the statistical significance of findings in Table 7 as well as an alternative, less subjective identification strategy for asset purchase news) also suggest that LSAPs if anything largely work through expected rates or frictionless term premiums rather than liquidity.

C. An Alternative Lens on Expected Inflation Derived from ATSMs

As another application, consider market-implied expected inflation, $ei_{n,t}$, as the spread between the nominal- and TIPS-based frictionless expected short rates over horizon n following:

$$ei_{n,t} = \tilde{y}_{n,t}^{f} - \tilde{y}_{n,t}^{TIPS,f}. \tag{11}$$

That is, $\tilde{y}_{n,t}^{TIPS,f}$ follows from a similar ATSM as in equations (5)–(9) but applied to TIPS (Durham (2023)), with a LF unique to the index-linked market to strip out TIPS liquidity and real term premiums from observed TIPS yields, using the first four orthogonal principal components of the TIPS yield curve as additional

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[23] Intraday changes are a persuasive empirical alternative. But as Gagnon et al. ((2011), p. 19) argue, the wider daily, if not 2-day, interval addresses the "novelty" and "diversity of beliefs" of the asset-purchase tool that plausibly imply a slower "absorption." Then again, strictly close-to-close daily changes include price movements up to the (commonly afternoon) announcements that are not germane to capturing the lower frequency nature of the response.

[24] The list includes Sept. 18, 2013, when Swanson ((2021), p. 34)) argues that "financial markets widely expected the FOMC to begin tapering its LSAPs, but the FOMC decided not to do so."

[25] Still, the largest daily drop in the liquidity premium, about 37 bps on Sept. 23, 2009, is also perhaps telling, in terms of the limits of the effects of the mere magnitude of purchases on market liquidity. The FOMC announced a slowing in the pace of purchases "to promote a smooth transition in markets," amid their observation that "economic activity has picked up." Correspondingly, the estimated frictionless term premium increased by about 45 bps, consistent with a "hawkish" surprise.

TABLE 7
Major QE and Unconventional Monetary Policy Announcements

Table 7 updates and expands event studies around subjectively selected policy announcements, following the initial use of daily responses in Gagnon et al. (2011), for 25 key dates that span Nov. 25, 2008, to Mar. 23, 2020, referenced across six studies. Daily changes listed below are in bps. Figures in bold denote cumulative daily changes.

Changes:	10-Year Yields	2-Year Frictionless Expected Rate	10-Year Frictionless Expected Rate	10-Year Frictionless Term Premium	10-Year Liquidity Premium
11/25/2008	−22	−5	−4	−24	4
12/1/2008	−19	−15	−11	−29	14
12/16/2008	−27	3	0	−18	−6
1/28/2009	13	8	7	18	−8
3/18/2009	−49	−11	−11	−42	0
8/12/2009	8	−11	−8	14	0
9/23/2009	−2	15	6	46	−36
11/4/2009	6	−5	−3	9	0
8/10/2010	−7	−5	−4	−9	3
8/27/2010	18	14	9	51	−28
9/21/2010	−13	−6	−6	−15	4
10/15/2010	7	−9	−7	10	2
11/3/2010	−2	−11	−8	−3	4
8/9/2011	−7	−7	−5	−7	4
8/26/2011	−4	−2	−2	−3	0
9/21/2011	−10	11	9	−26	5
6/20/2012	5	7	4	18	−12
9/13/2012	−4	−5	−4	−10	5
12/12/2012	5	−13	−7	−15	18
9/13/2013	−3	−8	−5	−22	16
12/18/2013	7	−24	−13	−42	43
12/17/2014	7	3	4	−9	9
3/18/2015	−12	−10	−10	5	−6
3/16/2020	−26	1	−2	0	−16
3/23/2020	−7	1	−1	5	−8
Gagnon et al. (2011)	**−92**	**−20**	**−24**	**−27**	**−31**
Wright (2012)	**−121**	**−34**	**−33**	**−97**	**−2**
Krishnamurthy and Vissing-Jorgensen (2011)	**−104**	**−20**	**−20**	**−95**	**5**
D'Amico et al. (2014)	**−63**	**−9**	**−10**	**−62**	**−1**
Swanson (2021)	**−69**	**−75**	**−50**	**−170**	**97**
Rebucci et al. (2022)	**−33**	**2**	**−4**	**5**	**−24**
Total (cum. sum of selected days)	**−138**	**−84**	**−71**	**−97**	**9**

pricing factors.[26] Furthermore, it follows that so-called breakeven inflation or inflation compensation—the observed spread between nominal and TIPS yields—is the sum of expected inflation, the frictionless inflation risk premium, and the relative liquidity loadings across nominals and TIPS, as in,

$$(12)\quad \underbrace{y_{n,t}-y^{TIPS}_{n,t}}_{\text{"}TIPS\text{ breakeven"}} = \underbrace{\tilde{y}^{f}_{n,t}-\tilde{y}^{TIPS,f}_{n,t}}_{ei_{n,t}} + \underbrace{tp^{f}_{n,t}-tp^{TIPS,f}_{n,t}}_{\text{"frictionless inflation risk premium"}} + \underbrace{l_{n,t}-l^{TIPS}_{n,t}}_{\text{"relative liquidity loadings"}}.$$

The relative merits are debatable. But there are at least three distinctive features of this approach compared to previous ambitious ATSMs that attempt to identify expected inflation. First, these frictionless measures strictly reference observable rather than latent factors, as opposed to DKW. Second, this approach uses zero information beyond market data, including neither survey data, as in

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[26] Note that the third bracketed term on the right-hand side of the identity is not the relative TIPS liquidity premium, but the relative liquidity loading across nominals and TIPS.

DKW, nor realized inflation series, as in AACMY, to pin down model parameters.[27] Third, expected inflation, equation (11), does not rest on joint estimation of the model(s) across nominal USTs and TIPS, and the pricing factors are thereby more flexible, yet hardly preclude overlaps across the factor structures.

To illustrate the results,[28] consider longer-run inflation expectations germane to the price stability goal of the Federal Reserve. The solid blue line in Graph A of Figure 9 shows the gap between the expected frictionless nominal 5-year forward rate beginning in 5 years (5Y5Y) based on the model and the corresponding estimates following equations (5)–(9) for TIPS updated from Durham (2023), which comprises a market-based proxy for the equilibrium real interest rate, or r-star.[29] For comparison, the dotted black line shows the corresponding DKW estimate of expected inflation at the same horizon, alongside long-run CPI survey forecasts from Blue Chip. Data across equation (11) and DKW beginning on July 29, 1999, produces means and standard deviations of 1.95% and 2.60% and 49 bps and 26 bps, respectively, for the two long-run expected inflation series, as listed in Panel A of Table 8. Therefore, this approach produces somewhat lower and more volatile estimates, strictly, compared to DKW.

An inference is that this alternative estimate implies more pessimism among investors during the last couple decades that the Federal Reserve would undershoot its long-run inflation objective, perhaps in contrast to received wisdom about monetary policy credibility. Even so, the daily series are positively but not very closely correlated, with a coefficient of 0.41, as listed in Panel B of Table 8. In fact, the frictionless series implies far less anchored inflation expectations at key points in the sample—namely, to the downside in the wake of the GFC and to the upside at times in the aftermath of COVID-19, as highlighted in Graph B of Figure 9.[30]

Furthermore, Graph C of Figure 9 shows the corresponding estimates for the 5-year horizon, alongside survey-based, 1-year-ahead CPI inflation forecasts from Consensus Economics, as well as 5-year-ahead projections from Blue Chip. The first and second moments of the ATSM-based estimates differ more at this shorter horizon, with means of 1.55% and 2.40% and standard deviations of 85 bps and 38 bps for the frictionless and DKW measures, respectively, also listed in Panel A of Table 8. Also, by visual inspection, and perhaps especially at the sample extremes of the GFC and the post-COVID-19 environment, the frictionless 5-year measure more closely follows the 1-year survey mean. As listed in Panel B of Table 8, the sample correlation between the frictionless measure at this horizon and the Consensus measure is about 0.62, whereas the corresponding figure using the DKW series is about 0.18. By contrast, as expected given that the DKW model uses Blue Chip data to estimate the parameters, the correlation between the 5-year DKW

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[27] Setting aside whether nonmarket information helps capture inflation expectations of all economic agents, this method more precisely isolates anticipated inflation among investors.

[28] Parameter estimation across a longer time series for nominals than for TIPS is arguably not ideal, but note that DKW, for example, backfill their estimates for earlier periods before TIPS issuance.

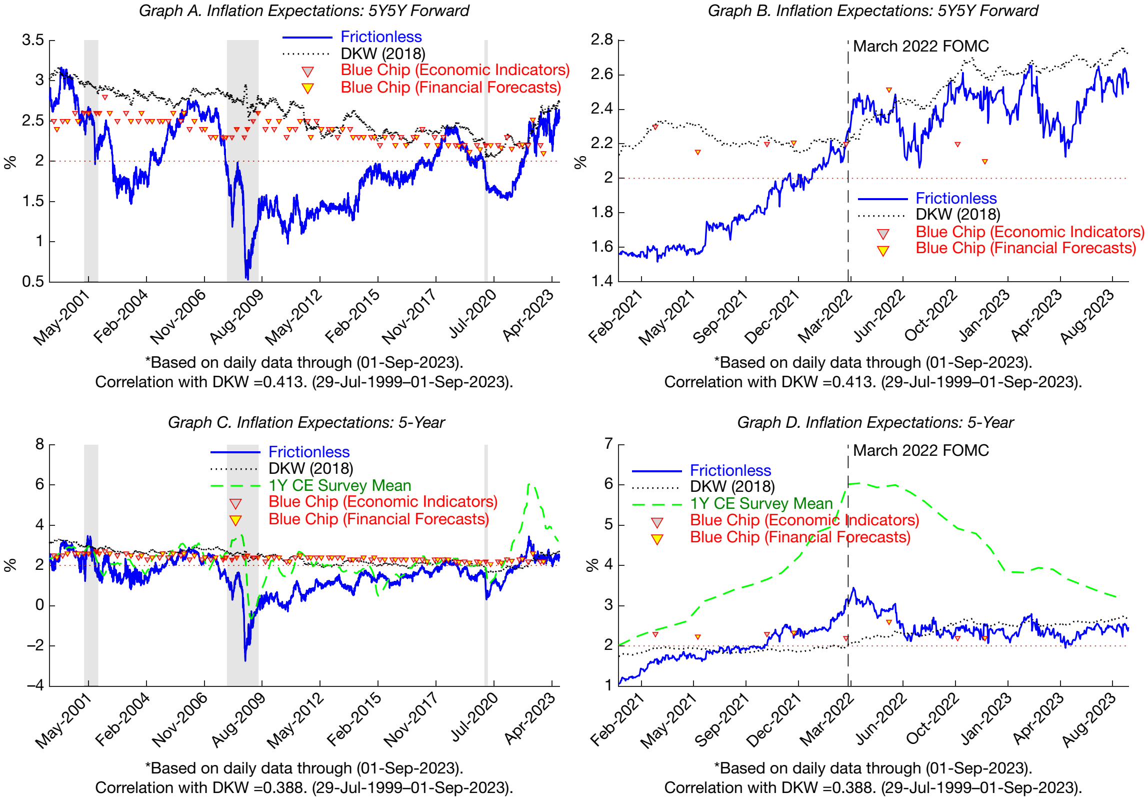
[29] See Durham (2023) for further details.

[30] Other measures of long-run TIPS-based inflation expectations include Christensen, Lopez, and Rudebusch (2010), who do not estimate liquidity premiums across TIPs or nominals. Also, the estimates from AACMY are notably inert and pinned near the Federal Reserve's price-level target for their full sample.

FIGURE 9

Measures of Expected Inflation

The solid blue lines in Graphs A–D of Figure 9 show implied expected inflation based on the difference between the frictionless expected nominal short rate and similar estimates of the frictionless expected real short rate from Durham (2023), at the 5-year-forward (Graphs A and B) and 5-year horizons (Graphs C and D). The dotted black lines are the corresponding estimates from DKW, and the gray- and yellow-shaded triangles show corresponding inflation expectation measures from the Blue Chip Economic Indicators and Financial Forecasts surveys, respectively. The dashed green lines in Graphs C and D are mean 1-year ahead expected inflation measures from Consensus Economics (CE).



*Based on daily data through (01-Sep-2023).
Correlation with DKW =0.413. (29-Jul-1999–01-Sep-2023).

*Based on daily data through (01-Sep-2023).
Correlation with DKW =0.413. (29-Jul-1999–01-Sep-2023).

*Based on daily data through (01-Sep-2023).
Correlation with DKW =0.388. (29-Jul-1999–01-Sep-2023).

*Based on daily data through (01-Sep-2023).
Correlation with DKW =0.388. (29-Jul-1999–01-Sep-2023).

TABLE 8

Measures of Inflation Expectations: Levels and Correlations

Panel A of Table 8 shows summary statistics of inflation expectation measures, following equation (11) and other metrics, for all available data from July 29, 1999, to Sept. 1, 2023. Panel B shows selected correlations across these measures over the same period.

Panel A. Summary Statistics

	Mean (%)	Std. Dev. (%)	Minimum (%)	Maximum (%)	Start Date	End Date
Frictionless 5Y	1.56	0.85	−2.75	3.46	29-Jul-99	1-Sep-23
DKW (2018) 5Y	2.40	0.38	1.64	3.32	29-Jul-99	1-Sep-23
Blue Chip (EI&FF) 5Y	2.37	0.14	2.08	2.70	1-Dec-99	1-Dec-22
Consensus Economics 1Y	2.29	0.97	−0.66	6.05	9-Aug-99	14-Aug-23
Frictionless 5Y5Y	1.96	0.49	0.53	3.16	29-Jul-99	1-Sep-23
DKW (2018) 5Y5Y	2.60	0.26	2.04	3.16	29-Jul-99	1-Sep-23
Blue Chip (EI&FF) 5Y	2.38	0.15	2.10	2.80	1-Dec-99	1-Dec-22

Panel B. Pairwise Correlations

Measure	Correlation
Frictionless 5Y and DKW (2018) 5Y	0.39
Frictionless 5Y and Blue Chip (EI&FF) 5Y	0.14
Frictionless 5Y and Consensus Economics 1Y	0.62
DKW (2018) 5Y and Blue Chip (EI&FF) 5Y	0.62
DKW (2018) 5Y and Consensus Economics 1Y	0.18
Frictionless 5Y5Y and DKW (2018) 5Y5Y	0.41
Frictionless 5Y5Y and Blue Chip (EI&FF) 5Y5Y	0.09
Frictionless 5Y5Y and Consensus Economics 1Y	0.47
DKW (2018) 5Y5Y and Blue Chip (EI&FF) 5Y5Y	0.70
DKW (2018) 5Y5Y and Consensus Economics 1Y	0.08

estimate and the corresponding Blue Chip survey average is about 0.62, clearly greater than the correlation using the frictionless estimate, around 0.14. Finally, as highlighted in Graph D of Figure 9, both the frictionless 5-year and the Consensus survey measure imply that inflation expectations began to increase markedly in the run-up to the Federal Reserve's liftoff from zero rates in Mar. 2022, intuitively as price pressures had mounted. By contrast, the DKW 5-year gauge was largely unchanged until after the tightening cycle began.

V. Discussion and Extensions

This novel ATSM of nominal UST yields features an observable LF based on pricing anomalies in individual securities and exclusively relies on market quotes. Besides the close model fit, the LF loadings on both yields and returns, second only in magnitude to the level factor, as well as other analyses connote that the near-ubiquitous assumption of frictionless government bond markets is problematic. Furthermore, the corresponding decompositions of yields follow intuition and correlate reasonably closely with other common measures, including KW and ACM. For example, the results confirm the persistent net downtrend in anticipated short rates as well as net lower required compensation for owning nominal USTs over the last few decades.

However, the divergence in estimated decompositions at key sample points, particularly the finer parsing of required excess returns into frictionless term and liquidity premiums, raise new questions about supposed countercyclicality of term premiums. Contrary to previous findings in an inconclusive literature, any countercyclicality appears to owe to compensation for absolute liquidity risk in nominal USTs. Also, the results afford a more precise assessment of LSAP effects on the yield curve, lending some support to the "portfolio rebalance" as well as "signaling" channels, but with ambiguous results for liquidity premiums, and in turn market functioning. Finally, in conjunction with similar estimation of TIPS, this approach produces alternative readings on expected inflation, including at horizons germane to the Federal Reserve's long-run price objective, which imply less sanguine inferences about anchoring at critical monetary junctures.

There is no shortage of caveats and possible extensions. These include difficult choices in the LF construction, related to conditional error specification as well as the precise estimation of error-correction speeds. In terms of applications, even more ambitious models that jointly estimate liquidity and frictionless premia across both USTs and the local equity market (say, as extensions of Lemke and Werner (2009), Lettau and Wachter (2011), or Adrian, Crump, and Moench (2015)) might uncover more comprehensive inferences about cyclicality and hedging demand, as opposed to ATSMs models solely informed by government bond data. Also, although the event-study-based estimates might capture the initial response of yield components to LSAPs, an open question regards the subsequent real effects, if any, of these quantities within wider financial conditions, broadly along the broad lines of, say, Gertler and Karadi (2015), Adrian, Boyarchenko, and Giannone (2019), or Kaminska, Mumtaz, and Sustek (2021). Finally, although the analyses comprise a novel pure-market-based gauge of inflation expectations, alternative methods that simultaneously estimate liquidity premia across TIPS and nominals, again with information on the latter market to advance AACMY, would comprise another welcome read on one of the most critical unobservable variables in financial economics.

Supplementary Material

To view supplementary material for this article, please visit http://doi.org/10.1017/S0022109023001345.

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