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The pricing of U.S. Treasury floating rate notes

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ABSTRACT

Since January 2014, the U.S. Treasury has been issuing floating rate notes (FRNs). These notes pay quarterly interest based on an average of the constant maturity rates of newly issued three-month T-bills during the quarter. We show how to price such FRNs. We estimate that they have been paying excess interest between 3 and 42 basis points above the implied interest of other Treasury securities. We interpret this fact through the lens of a model where money-like assets differ in their degrees of moneyness. Additional empirical evidence supports this interpretation.

1. Introduction

In 2014, 2-Year U.S. Treasury Floating Rate Notes (FRNs) became the newest product to be issued by the U.S. since Treasury Inflation Protected Securities (TIPS) in 1997. The U.S. Treasury announced the issuance of floating rate notes in 2013 with the partial aim to reduce Treasury bill issuance amid concerns with rollover risk (in 2008, Treasury bills represented nearly 30% of public debt outstanding compared to 18% as of June 2023). Another stated objective was "saving taxpayer dollars by financing the government's borrowing needs at the lowest cost over time" (U.S. Department of the Treasury, 2014). In this paper we estimate the interest paid by FRNs that have been issued relative to other financing sources.

After an initial ramp up of Treasury FRN issuance, since 2016, the amount of FRN debt outstanding has been increasing slowly to exceed $550 billion in 2023 (Fig. 1). This represents 2.4% of the total U.S. Treasury outstanding marketable debt as of June 2023 (Fig. 2). By comparison, TIPS represent 7.8% of total marketable debt, Treasury bills 18%, notes 55.2%, and bonds 16.7%.

Treasury FRNs are issued at monthly auctions with a maturity of two years. They promise quarterly coupon payments indexed to the three-month T-bill rates determined at weekly auctions. Unlike generic FRNs or typical floating rate bank loans, the Treasury's FRNs pay a coupon that is an average of the constant maturity three-month rates. This implies that a FRN issued at par requires a spread (positive or negative) even if priced through a frictionless no-arbitrage approach. Based on Treasury yield curves on auctions dates, we estimate this spread.

Over the period 2014 to 2023 H1, estimated spreads have been negative for 85% of all auctions, with an overall average of −4 basis points (bps) in annualized terms. Before 2019, spreads have been almost exclusively negative. This is consistent with the fact that forward curves for maturities of two years and less have typically been upward sloping until 2019. In this case, averaging interest rates over a quarterly coupon period makes the FRN more valuable and the spread required for a par value has to be negative. More recently, the shape of the forward curves has been more variable, and estimated spreads have been positive more often.

Actual FRN spreads determined at Treasury auctions have been positive (or zero) except for the first half of 2022. Put together, the spreads paid in excess of the estimated no-arbitrage spreads average 14 bps, with a range of 3 to 42 bps. Excess spreads were particularly high in early 2016, in 2019, and early 2020; they also reached relatively high

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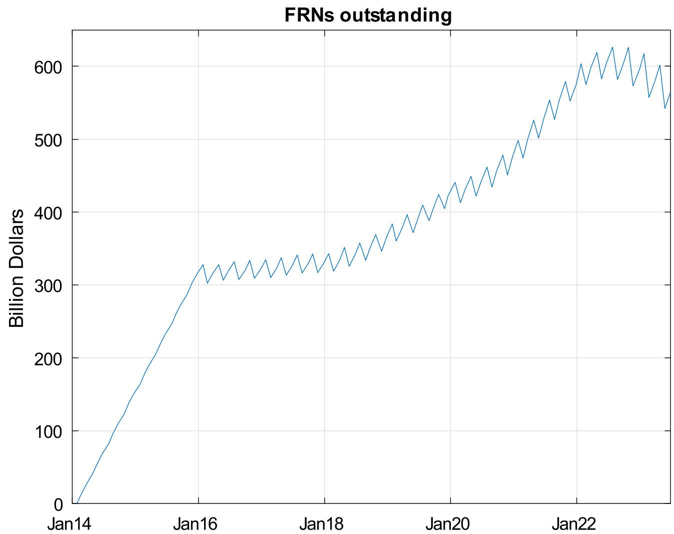

Fig. 1. Source: https://www.treasurydirect.gov/auctions/auction-query/.

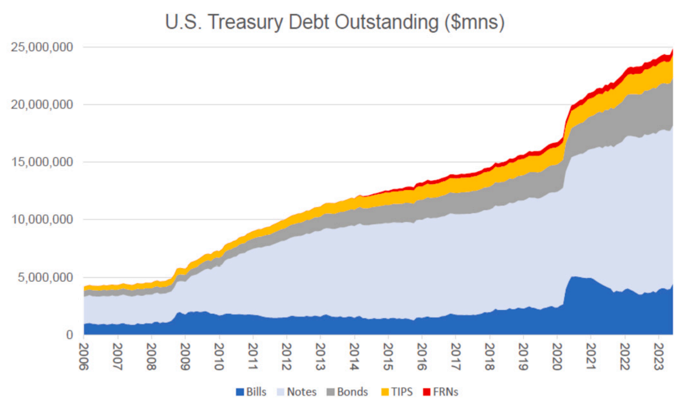

Fig. 2. Source: https://fiscaldata.treasury.gov/datasets/monthly-statement-public-debt/summary-of-treasury-securities-outstanding. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

levels in late 2022. Our findings clearly reject the idea that positive excess spreads were just a short-lived phenomenon associated with the introduction of a new type of Treasury security. On the other hand, our estimates are not inconsistent with excess spreads trending down very slowly over time. The annual excess borrowing costs for the Treasury implied by these spreads have exceeded 400 million dollars every year since 2016.

Conceptually, no-arbitrage pricing of Treasury FRNs requires a convexity adjustment to deal with the constant maturity index. We derive the exact pricing formula and evaluate it with a version of the Black et al. (1990) model. We find a very small convexity adjustment so that accurate pricing of Treasury FRNs is possible without it. However, the convexity adjustment has increased significantly since 2022. We show under what conditions this adjustment could no longer be ignored.

Compared to an investment strategy of rolling over T-bills, we find that the returns to FRNs have been attractive to investors. The average realized excess return of FRNs over the rolled-over T-bills strategy is close to the average ex-ante excess spread we have estimated. We also show that ex-ante excess spreads positively predict realized excess returns of FRNs over the T-bill strategy.

We interpret our empirical finding within a dynamic pricing model where investors derive utility from money-like securities. FRNs offer investors some utility but are less money-like than T-bills. We characterize excess spreads in FRNs. Based on guidance from this model, we empirically evaluate potential drivers of these excess spreads. We find significant roles for OIS - T-bill and LIBOR - T-bill spreads, as well as implied interest rate volatility. Consistent with the model, excess spreads have mostly been declining in the outstanding maturity of FRNs.

We contribute to studying the market conditions for the U.S. FRNs. Greenwood et al. (2016) note that initial yields on FRNs have been higher than three-month T-bill rates. They do not price FRNs. Bhanot and Guo (2017) find substantial excess returns using secondary market data through 2016 for 2-Year U.S. Treasury FRNs. To our knowledge, our paper is the first study to price U.S. Treasury FRNs and estimate the Treasury's excess borrowing costs due to FRNs. We are also not aware of other studies containing our pricing equations with explicit convexity adjustments needed due to the constant maturity index in the U.S. FRNs.[1]

Several studies have documented convenience yields in Treasuries, for instance, Krishnamurthy and Vissing-Jorgensen (2012) or Greenwood et al. (2015); more recently Treasuries have also experienced episodes characterized by inconvenience yields, He et al. (2022) and Klingler and Sundaresan (2023). We focus on how the pricing of FRNs is affected by different dimensions of the money-like services that give Treasuries convenience yields.

Subsequent to previous versions of this paper, Fleckenstein and Longstaff (2020) have also considered the pricing of Treasury FRNs. They form replicating portfolios of Treasury FRNs with other Treasury securities and two types of swaps. As we show in Section 5, their approach suffers from the extreme illiquidity of the instruments they use to construct replicating FRNs. Their replication also uses interest rate swap quotes which the literature has widely documented to be inconsistent with the absence of arbitrage relative to Treasuries.

In the rest of the paper, Section 2 estimates the Treasury's borrowing costs for FRNs. Section 3 derives and estimates convexity adjustments. This is followed by the comparison of rolled-over T-bill investments to FRNs in Section 4 and the examination of FRN replications with swaps in Section 5. Section 6 interprets our findings through the lens of an infinite-horizon pricing model with convenience yields and documents empirical drivers of the estimated spreads.

2. Treasury FRN pricing at auctions

In this section, we value Treasury FRNs at auction dates and compare the valuations to the actual pricing of these FRNs. The Treasury started issuing FRNs with a maturity of two years in January 2014. These notes promise quarterly coupons indexed to the 13-week T-bill rates. New FRNs are issued towards the end of January, April, July, and October. There are reopening auctions in the two months following a new issuance where additional amounts of the previously issued FRNs are sold.

Newly issued FRNs have typically been sold at par with the auction determining a spread that is added to the index of three-month T-bill rates. Unlike generic FRNs or typical floating rate bank loans, Treasury FRNs pay a coupon that is based on an average of the constant maturity three-months rates. This section shows how this feature affects the no-arbitrage price and compares it to the price of a generic FRN.

[1] Pricing anomalies have been studied in many areas of the market for U.S. Treasury securities, namely in the market for off-the-run vs. on-the-run Treasury bonds (Krisnamurthy, 2002), TIPS (Fleckenstein et al., 2014), longer maturity Treasury bonds (Cornell and Shapiro, 1989), callable Treasury bonds (Carayannopoulos, 1995), and from an international perspective (Du et al., 2017). Price impacts due to recent policy or regulatory measures have been documented by Vissing-Jorgensen and Krishnamurthy (2011), D'Amico and King (2013), and Du et al. (2018), Hartley (2017), and Cochrane (2017).

We value a new FRN as

$$V_0 = \sum_{I=0}^{7} \frac{\frac{1}{13}\sum_{k=0}^{12}\left(r_{0,13I+k}^{f,13} + \frac{1}{4}\theta_0\right)}{1 + r_0^{13I+13}} + \frac{1}{1 + r_0^{104}}, \tag{1}$$

where $r_{0,13I+k}^{f,13}$ stands for the current (time 0) forward rate with a 13-week maturity for week $13I + k$, and r_0^{13I+13} the current zero-coupon rate with a maturity of $13I + 13$ weeks. In the next section, we derive the no-arbitrage value of a FRN in a more rigorous way and demonstrate that Equation (1) represents a very accurate pricing formula. This formula can be evaluated based on the current term structure alone due to the no-arbitrage relation between forward rates and spot rates

$$1 + r_{0,I+k}^{f,13} = \frac{1 + r_0^{I+k+13}}{1 + r_0^{I+k}}. \tag{2}$$

The starting dates of each forward rate period correspond to a weekly auction date of 13-week T-bills whose rates determine the coupon payments of the FRN. The discount factors $1/\left(1 + r_0^{13I+13}\right)$ correspond to the quarterly (13-week) coupon payment dates. We assume a constant spread θ_0 (in annualized terms) which will be determined so that the value of the FRN is at par, $V_0 = 1$.

Compare this to a more standard FRN where the coupon payment is based on the interest rate corresponding to the same period. The price of a standard FRN, $\tilde{V}_0$, with the same maturity and coupon payment dates would be

$$\tilde{V}_0 = \sum_{I=0}^{7} \frac{r_{0,13I}^{f,13} + \frac{1}{4}\tilde{\theta}_0}{1 + r_0^{13I+13}} + \frac{1}{1 + r_0^{104}}.$$

Substituting the definition of the forward rates as in Equation (2), this becomes

$$\tilde{V}_0 = 1 + \tilde{\theta}_0 \sum_{I=0}^{7} \frac{1/4}{1 + r_0^{13I+13}}.$$

A FRN sold at par, $\tilde{V}_0 = 1$, does not require a spread, $\tilde{\theta}_0 = 0$. Therefore, the spread we estimate in a Treasury FRN captures the effect of using a constant maturity index.

Equation (1) is evaluated, and solved for θ_0, based on the term structure on an auction date. We use the Treasury-implied zero-coupon yields from Reuters with maturities $1, 3, 6, 9, 12, 24$ and 36 months.[2] Yields are interpolated by cubic splines. For reopening auctions, Equation (1) is modified to take into account the reduced maturity, accrued interest, and the fact that, with the spread predetermined at the initial auction, prices are typically no longer at par.

2.1. Results

Over the period 2014 to 2023 H1, we estimate spreads θ to be between −25 and 14 bps in annualized terms for new auctions and reopenings. For 85% of all auctions, estimated spreads have been negative, with an overall average of −4 bps. Before 2019, spreads have been almost exclusively negative. This is consistent with the fact that forward curves for maturities of two years and less have typically been upward sloping until 2019. In this case, averaging interest rates over a quarterly coupon period makes the FRN more valuable and the spread θ required for a par value has to be negative. More recently, the shape of the forward curves has been more variable, and spreads θ have been positive more often.

[2] In earlier versions of the paper, we have also considered term structure data from the close of the day before the auction and of the auction date, and then averaged the prices. Differences between the two dates were very small. The auction deadline is at 11:30am. Using yield curve data based on Gurkaynak et al. (2007) produced very similar estimates.

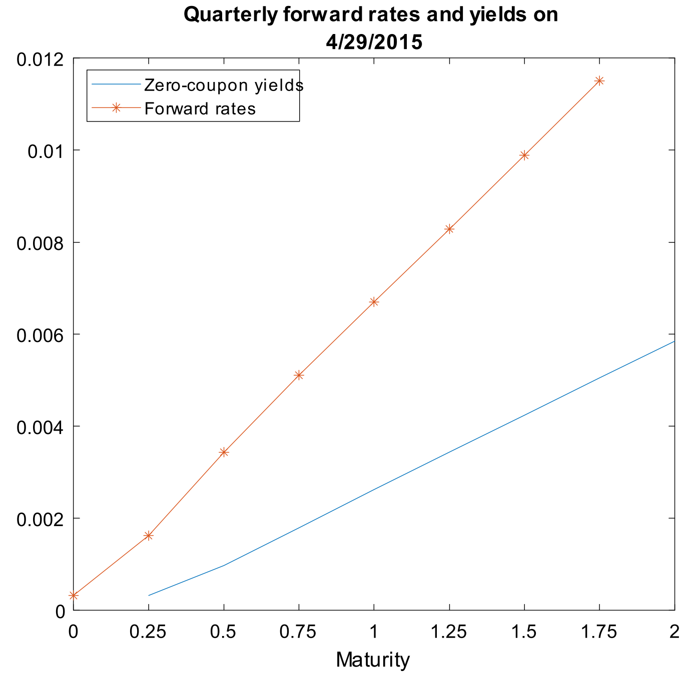

Fig. 3. Example of the term structure of Treasury yields and forward rates on an auction date for a new FRN issue. The upward sloping forward rate curve makes the Treasury FRNs more valuable, and, from a no-arbitrage perspective, requires a negative spread.

To get a better sense of how the spread θ is determined, consider, for instance, the term structure on 4/29/2015, the date of a new auction. As shown in Fig. 3, forward rates are almost linear in maturity up to two years. A generic FRN promises quarterly coupons with risk-neutral expected values equal to the forward rates (here annualized) at the beginning of the period, that is forward rates determined at 0, 0.25 etc. until 1.75 in the figure. This FRN would be valued at par. At the end of each quarter, the forward rate is on average about 16 bps higher than at the beginning, so that averaging over the period increases the coupon value by about 8 bps. To have FRNs priced at par, θ should be set to approximately −8 bps. The exact θ based equation on (1) is close, namely at −7.3.

Based on the logic that the spread θ can be approximated by averaging half the difference between the forward rates at the beginning and end of quarter, the approximation simplifies to

$$-\frac{1}{16}\left(\bar{r}_{0,2Y}^{f,13wks} - \bar{r}_0^{13wks}\right), \tag{3}$$

namely, the 2-year forward minus the spot rate divided by 16 (note, for convenience, these forward rates are in annualized terms, indicated by the upper bar $\bar{r}$). For the April 2015 issue auctioned on 4/29/2015, this equals −8.03 bps, compared to −7.3 bps for the exact θ. Considering all new issues, the difference in absolute values between the exact θ based equation (1) and the approximation in equation (3) has been at most 1.6 bps and has been below 1 basis point for 34 of the 38 new issues since 2014. So, this can serve as a basic back-of-the-envelop benchmark.

Actual pricing spreads determined by Treasury auctions have been positive except for 2022 H1. We define the *excess spread* as the auction-determined spread minus the no-arbitrage spread, θ. The excess spread represents the annualized interest cost the Treasury is paying for FRNs in excess of the interest cost implied by the term structure of other Treasury securities. Fig. 4 shows the time series of these spreads for 2014-2023 H1. Excess spreads range between 3 and 42 bps with an average over all auction dates of 14 bps. To return to our example, the April 2015 issue had $\theta = -7.3$ bps, the auction determined spread was

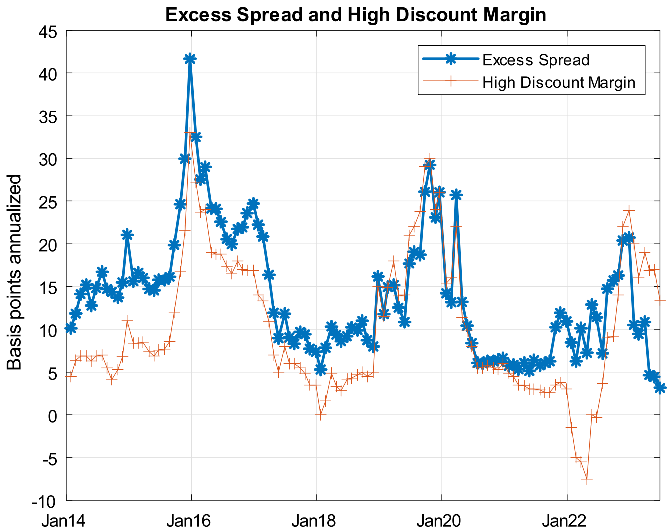

Fig. 4. The excess spread is defined as the spread included in a FRN minus the spread that would be justified by ruling out arbitrage at auction dates.

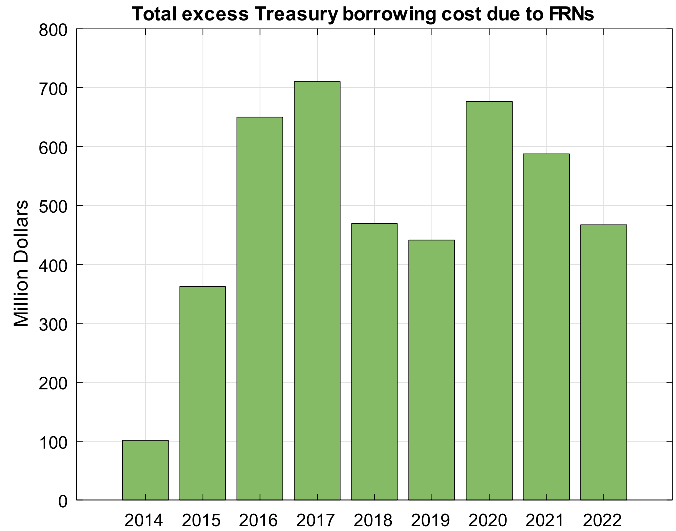

Fig. 5. Total excess Treasury borrowing costs due to FRNs are computed by combining the total amount of FRNs outstanding with the excess spreads determined at each auction date.

7.4 bps, so that the excess spread amounts to 14.7 bps. Excess spreads were particularly high in early 2016, in 2019, and early 2020; they also reached relatively high levels in late 2022. The figure clearly rejects the idea that positive excess spreads were a short-lived phenomenon associated with the introduction of a new type of Treasury security. On the other hand, the figure is not inconsistent with excess spreads trending down very slowly over time.

As shown in Fig. 4, a substantial part of the variation in the excess spread is captured by the High Discount Margin, HDM, which is used by the Treasury to auction FRNs. In particular, for new auctions, the HDM becomes the spread that is applied to a FRN which is sold at par. For reopenings, the HDM determines the price of a FRN according to the Treasury's formula (Department of the Treasury, 2013). HDMs are less closely associated with excess spreads starting in 2022.

In early 2022, actual FRN spreads turned negative for the January and April 2022 issues. Fig. 4 shows the negative High Discount Margins associated with these auctions. The estimated no-arbitrage spreads θ for these two auction dates were even more negative, which explains the positive excess spreads shown in Fig. 4. At that time, the term structure was steeply upward sloping, justifying a very negative θ as illustrated by Equation (3).

At a given point in time, there are FRNs from up to 24 issue dates outstanding. We have estimated the excess spread for each issue. Multiplying these by the corresponding amounts issued gives us the total excess borrowing cost associated with all outstanding FRNs at a given time. Fig. 5 reports excess borrowing costs for each calendar year. In each year since 2016, the excess borrowing cost has exceeded 400 million dollars. The highest excess cost of just over 700 million was incurred in 2017, as excess spreads for FRNs outstanding at the time were particularly high.

3. No-arbitrage pricing of FRNs with a constant maturity index

In this section we derive the no-arbitrage value of a Treasury FRN and demonstrate that Equation (1) is very accurate in a low volatility environment as in 2014-2021. The equation is slightly less accurate starting 2022 as interest rates have become more volatile, but from the perspective of this paper it remains sufficiently precise. We also show under what conditions a more involved pricing approach for FRN would be needed.

To rule out arbitrage, assume a state-price valuation process Λ_t.[3] The value of a Treasury FRN is given by

$$V_0 = \frac{1}{13}\sum_I \sum_k E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0} r^{13}_{I+k}\right] + E_0\left[\frac{\Lambda_{104}}{\Lambda_0}\right]$$

for $I \in 13\,[0:7]$ and $k \in [0:12]$. The period length is one week. At week $I+k$ rate r^{13}_{I+k} with a 13 week maturity is determined to be included in the coupon paid at $I+13$. Coupons are paid every 13 weeks. Pricing the FRN involves pricing 104 strips with payouts based on the rate set by the weekly auction of the 13-week T-bill. Rates are in effective terms so that r^{13}_{I+k} is a 13 week rate and coupon payments represent the average, thus the factor $1/13$.

Consider first the case of a coupon strip with $k=0$; the maturity date of the stochastic discount factor, Λ_{I+13}/Λ_0, and the payment date is the same as the maturity date of the interest index, namely $I+13$. In this case, starting for convenience with the strip including the principal,

$$\begin{aligned}
E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0}\left(1+r^{13}_I\right)\right] &= E_0\left[\frac{\Lambda_I}{\Lambda_0}\frac{\Lambda_{I+13}}{\Lambda_I}\left(1+r^{13}_I\right)\right] \\
&= E_0\left[\frac{\Lambda_I}{\Lambda_0}E_I\left\{\frac{\Lambda_{I+13}}{\Lambda_I}\left(1+r^{13}_I\right)\right\}\right] \\
&= E_0\left[\frac{\Lambda_I}{\Lambda_0}\right] = \frac{1}{1+r^I_0},
\end{aligned}$$

and adjusting for the principal

$$\begin{aligned}
E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0}r^{13}_I\right] &= E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0}\left(1+r^{13}_I\right)\right] - \frac{1}{1+r^{I+13}_0} \\
&= \frac{1}{1+r^I_0} - \frac{1}{1+r^{I+13}_0}.
\end{aligned}$$

[3] This no-arbitrage valuation is robust to the possibility of default. Specifically, assume a default is associated with a uniform principal write-down of all Treasuries. The process for the cumulative default write-down can be denoted by X_t, and an adjusted state-price process defined as $\Lambda_t X_t$ can be used to price all Treasury debt. This adjustment parallels the standard change of measure from a real to a nominal price process where inflation acts as a uniform principal write-down on nominal debt. We thank a referee for suggesting this point.

Clearly, the strip can be priced easily from current spot interest rates with the appropriate maturities.

This can be rewritten as

$$E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0} r_I^{13}\right] = \frac{1}{1+r_0^{I+13}} \frac{1+r_0^{I+13}}{1+r_0^I} - \frac{1}{1+r_0^{I+13}} = \frac{r_{0,I}^{f,13}}{1+r_0^{I+13}}$$

with the forward rate defined as $\left(1+r_{0,I}^{f,13}\right) \equiv \frac{1+r_0^{I+13}}{1+r_0^I}$. This is the rate between I and $I+13$ that can be locked in as of now by buying a zero coupon bond with a maturity of $I+13$ and borrowing the purchase price until period I. Intuitively, the forward rate, is the certainty equivalent or the expected future interest rate under the risk-neutral distribution. It is discounted with the spot interest rate corresponding to the coupon payment date.

For the general case $k > 0$, the pricing process can no longer be eliminated. As shown in the Appendix A, the no-arbitrage value of a strip can be written as

$$E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0} r_{I+k}^{13}\right] = \frac{r_{0,I+k}^{f,13}}{1+r_0^{I+13}} + Cov_0\left(\frac{\Lambda_{I+k}}{\Lambda_0}\frac{1}{1+r_{I+k}^{13}}\left[r_{I+k,I+13}^{f,k} - r_{0,I+13}^{f,k}\right], r_{I+k}^{13}\right). \quad (4)$$

The first component represents the forward rate $r_{0,I+k}^{f,13}$ for the index determination date $I+k$, discounted at the current spot rate r_0^{I+13} with maturity $I+13$ which corresponds the date the payment is made, at the end of a quarterly period. The second term on the right-hand side is non-zero for all $k > 0$ and zero for $k = 0$. Indeed, for $k = 0$, the term in brackets $\left[r_{I+k,I+13}^{f,k} - r_{0,I+13}^{f,k}\right] = \left[r_{I,I+13}^{f,0} - r_{0,I+13}^{f,0}\right] = [0-0]$.

For strips with $k > 0$ a "convexity adjustment" is needed. To compute it requires a fully specified pricing process or term structure model. A similar adjustment has been used for pricing the CME's Eurodollar futures contracts with settlement at the beginning of an interest period (Veronesi, 2010, Section 21.7). As we show below, the adjustment for pricing Treasury FRNs has been small, in the order of significantly less than 1 basis point in annualized coupon equivalent terms. Therefore, Treasury FRNs can be effectively priced based on the current zero-coupon term structure alone – at least for the relatively low interest rate volatility environment FRNs have experienced so far.

To provide more intuition about the convexity adjustment, we can transform the value of a strip so that it does not explicitly depend on the pricing process Λ_t. Define the risk-neutral expectation operator E_0^Q implicitly as

$$\left(1+r_0^{I+13}\right) E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0} r_{I+k}^{13}\right] = E_0\left[\left\{\frac{\Lambda_{I+13}}{\Lambda_0} / E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0}\right]\right\} r_{I+k}^{13}\right] = E_0^{Q(I+13)}\left[r_{I+k}^{13}\right].$$

As shown in the Appendix A

$$E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0} r_{I+k}^{13}\right] = \frac{1}{1+r_0^{I+k}} E_0^{Q(I+k)}\left[\frac{r_{I+k}^{13}}{1+r_{I+k}^{13-k}}\right].$$

If one ignores for an instant the uncertainty associated with r_{I+k}^{13} and r_{I+k}^{13-k}, then this would simplify to $r_{0,I+k}^{f,13}/1+r_0^{I+13}$ as in Equation (1) above. With uncertainty, however, the expectation needs to be computed with a term structure model. A second-order Taylor approximation for $E_0^{Q(I+k)} r_{I+k}^{13}$ can give some intuition that does not rely on the state-price process Λ. As shown in Appendix A, to a second-order approximation,

$$E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0} r_{I+k}^{13}\right] \cong \frac{r_{0,I+k}^{f,13}}{1+r_0^{I+13}} + \frac{\left(1+r_{0,I+k}^{f,13}\right)^3}{1+r_0^{I+13}} Var_0^{Q(I+k)}\left(\frac{1}{1+r_{I+k}^{13}}\right) + \frac{1}{1+r_0^{I+k}} Cov_0^{Q(I+k)}\left(\frac{1}{1+r_{I+k}^{13-k}}, r_{I+k}^{13}\right). \quad (5)$$

The equation shows the convexity adjustment depending on conditional variances and covariances of short rates with at most 13-week maturity. Specifically, the adjustment corresponds to the conditional variance of the 13-week rate at week $I+k$ plus a covariance that is typically negative between the 13-week rate and the inverse of the rates of maturities 1 to 13.

3.1. Measuring the convexity adjustment

We represent the state-price valuation process Λ_t implicitly through a binomial tree of the short rate. The short-rate tree is specified along the lines of a simple version of the Black, Derman and Toy (BDT, 1990) model with constant interest rate volatility. The BDT model is widely used by practitioners for pricing interest rate derivative contracts. See Veronesi (2010) for a modern treatment. Specifically, the weekly short rate is specified as

$$r_{t+1} = r_t \exp(\mu_{t+1} + h^{1/2}\sigma\varepsilon_{t+1})$$

with ε_{t+1} equal to -1 or $+1$, each with a risk-neutral probability of 0.5, and $h = 1/52$. The time-dependent (known) factors μ_{t+1} are set so that spot rates for maturities ranging from 1 to 116 weeks exactly match the term structure. Refinitiv Eikon reports implied BDT volatilities for caps and for swaptions for various maturities and the corresponding zero-coupon yields. We set the volatility parameter σ based on the average of the reported volatilities across maturities ranging from 3 months to 2 years, and across caps and swaptions.

To illustrate the connection between the pricing process Λ_t and the BDT interest rate model, consider the price of a 2-period zero coupon bond

$$\frac{1}{1+r_0^2} = E_0\frac{\Lambda_1}{\Lambda_0}\left\{\frac{1}{1+r_1^1}\right\} = \frac{1}{1+r_0^1} E_0\left\{\frac{\Lambda_1}{\Lambda_0}/E_0\frac{\Lambda_1}{\Lambda_0}\right\}\left\{\frac{1}{1+r_1^1}\right\} = \frac{1}{1+r_0^1}\left\{\pi^*\frac{1}{1+r_1^1(u)} + \left(1-\pi^*\right)\frac{1}{1+r_1^1(d)}\right\},$$

with $r(u)$ and $r(d)$ the upwards and downwards realizations of the interest over the period. By recursively applying the BDT model, any risky payout can be priced as with the state-price process Λ_t.

Fig. 6 reports the model-implied convexity adjustment for each auction date in terms of an annualized spread, Δ_0, defined by

$$\sum_I \sum_k E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0} r_{I+k}^{13}\right] = \sum_I \sum_k \frac{r_{0,I+k}^{f,13} + \frac{1}{4}\Delta_0}{1+r_0^{I+13}}.$$

As shown in the figure, the convexity adjustment does not exceed 0.4 bps for any of the auction dates, and for most of the auctions it has been below 0.1 of a basis point. From the perspective of this paper, an adjustment of this magnitude is immaterial.

Table 1 explores the convexity adjustment as a function of the level of the interest rate and the volatility parameter. The first two lines use a volatility parameter σ of 0.5 with the term structure of the spot rates at a flat 1% or 1.5% in annualized terms. This case is representative of the conditions between 2014 and 2021. The convexity adjustment is

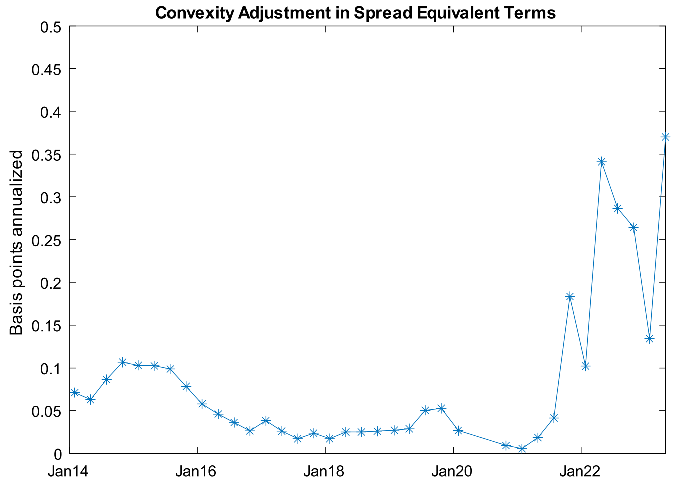

Fig. 6. The convexity adjustment is computed based on a version of the BDT model calibrated to the term structure and the interest rate volatility on auction dates.

Table 1
Convexity adjustment, Δ_0, as a function of the interest rate level and volatility. The term structure of the spot rates is set at a flat percentage of $\bar{r}$, σ is the volatility parameter. $\text{Std}_0\left(r_{1Y}^{13w}\right)$ and $\text{E}_0\left(r_{1Y}^{13w}\right)$ are the conditional standard deviation and the conditional expectation of the annualized 13-week rate one year from now. Moments are computed under the risk-neutral distribution.

$\bar{r}$ in %	σ	Δ_0 in bps	$\text{Std}_0\left(r_{1Y}^{13w}\right)$	$\text{E}_0\left(r_{1Y}^{13w}\right)$
1	0.5	.035	.53	1
1.5	0.5	.08	.79	1.5
3.8	0.45	.38	1.8	3.8
3.2	0.8	1.14	3	3.2

below 0.1 of a basis point. As σ represents the standard deviation of the natural logarithm of the short rate, we report as a more intuitive measure of interest rate volatility the conditional standard deviation of the 13-week rate one year in the future, $\text{Std}_0\left(r_{1Y}^{13w}\right)$. For the first two cases, this standard deviation equals 0.53 or 0.79 percent, in annualized terms. This low number is representative of the stability of short rates between 2014 and 2021.

The lower two lines contain examples with higher interest rates and higher volatility parameters. In particular, line three represents approximately the last data point of the sample, 6/29/2023. The short rate being higher at 3.8% implies a larger adjustment even with a similar volatility parameter σ. The last line shows a case that is representative of the peak volatility during the financial crises as represented by the BDT parameters for 10/10/2008. The convexity adjustment is 1.14 bps. The implied conditional standard deviation of the 13-week rate at a one-year horizon is 3%. Overall, the table shows that while the current relatively stable interest environment does not require a convexity adjustment for reasonably accurate pricing of Treasury FRNs, such an adjustment has the potential to become relevant with significantly higher interest rate volatility.

4. T-bill investment strategy

Based on the term structures at auction dates, we have concluded that FRNs have offered excessive interest, or equivalently, that they have been cheap to buy for investors. In this section, we consider the ex-post realized returns from investing in FRNs and compare these to a T-bill investment strategy that consists in holding 3-month T-bills until maturity. We find that FRNs investments have mostly outperformed 3-month T-bills. We also find a positive relation between our estimated excess spreads on FRNs and the subsequent realized excess returns of FRNs over 3-month T-bills.

A generic FRN can be perfectly replicated by rolled-over short-term investments. Because the Treasury's FRNs pay a coupon based on an average of the three-month T-bill rate, such perfect replication is not feasible. Replication with widely available derivative contracts also does not seem possible, as we discuss further in the next section. Given these constraints, we consider here the possibility of establishing near-arbitrage positions that replicate approximately the FRNs with investments in three-month T-bills.

The strategy we consider is to invest in three-month (13-week) T-bills by holding a bill until maturity, and by choosing bills with maturity dates as close as possible to coupon payment dates for FRNs. If the Treasury's FRN were of the generic type, this buy-and-hold strategy would perfectly replicate its cash flows, except for some minor mismatch in the maturity dates of the T-bill and the FRN. In a frictionless arbitrage-free environment, daily returns on a generic FRN and this short-term strategy would be equalized. Due to the interest averaging feature of the Treasury's FRNs, the replication is no longer perfect. The coupons of the FRNs are affected by within quarter changes in the constant-maturity 13-week T-bill rate, but these do not directly affect the cash flows of the approximate replication strategy.

We compute daily returns for FRNs and T-bills based on secondary market prices and accrued interest on FRNs. Secondary market close prices are obtained from Reuters Eikon, accrued FRN interest data is obtained from Treasury Direct. We identify 13-week T-bills that best match the coupon periods of the FRNs. These bills mature at the end of January, April, July and October, ranging from 1 April 2014 to April 2023.

Table 2 summarizes properties of this strategy. Average daily realized returns on the FRNs have exceeded the returns of the buy-and-hold T-bill investments for 26 out of the 30 FRN issues that have matured before the end of our sample. Excess returns of FRNs have on average been 15 bps in annualized terms. For comparison, our estimated excess spreads average 14 bps over all auctions, new issues and reopenings: the average excess spread for new issues only is 13.3 bps. These attractive ex-post returns confirm the conclusion from the ex-ante spreads that FRNs have been paying excess interest.

As shown in Fig. 7 there is a positive relation between our estimated excess spreads at auction dates and the subsequent realized excess returns of a FRN issue. In particular, the slope coefficient of the regression of the average excess returns on the excess spreads is 0.71 (p-value 0.03) with adjusted R-square of 0.12. It is interesting to consider the outliers in the upper left corner, corresponding to the issues of October 2020, January 2021 and April 2021. These issues experienced the dramatic and unexpected increase in short term interest rates during 2022, as the Fed responded to increased inflation. The quarterly coupons of FRNs are averages of the realized 3-month Tbill rates over the quarter, and rising T-bill rates therefore contribute to higher ex-post returns of FRNs. As is clear from the Fig. 7, the relation between ex-post returns and ex-ante excess spreads would be tighter without this surprise shock.

While the T-bill strategy can naturally be thought of as approximately replicating the returns of the FRNs, our analysis shows that at a daily frequency the replication is not very tight. Indeed, in the table, the standard deviation of the returns of the FRNs in excess of the T-bill investments over the whole sample is only moderately lower than the standard deviation of the FRNs themselves. To the extent that excess returns can be thought of as a long-short investment, the short T-bill investments did hedge the daily returns of the FRNs only very partially. This suggests that daily returns to FRNs were driven by other factors than just concurrent T-bill prices.

Bhanot and Guo (2017) document daily excess returns for FRNs up to October 2016 relative to a set of overnight rates, in particular, Federal Funds (FF) rates, Broad General Collateral Rates (BGCR), and

Table 2
FRNs vs 3-month T-bills. Returns are computed over trading days, in percentage points. Means are scaled by 250, standard deviations by the square root of 250. Excess returns are FRN returns minus T-bill returns.

FRN	FRN returns		T-bill returns		Excess returns		Nobs
	mean	std	mean	std	mean	std	
2014 Jan	0.10	0.04	0.03	0.02	0.07	0.04	498
2014 Apr	0.15	0.04	0.07	0.02	0.08	0.05	501
2014 Jul	0.19	0.05	0.09	0.03	0.09	0.05	500
2014 Oct	0.21	0.06	0.13	0.03	0.08	0.07	500
2015 Jan	0.30	0.07	0.16	0.04	0.14	0.08	501
2015 Apr	0.36	0.12	0.22	0.04	0.14	0.12	501
2015 Jul	0.49	0.14	0.33	0.05	0.16	0.14	501
2015 Oct	0.69	0.17	0.46	0.05	0.23	0.17	501
2016 Jan	0.92	0.10	0.58	0.06	0.34	0.10	504
2016 Apr	1.03	0.09	0.71	0.06	0.33	0.10	502
2016 Jul	1.23	0.11	0.91	0.07	0.32	0.11	505
2016 Oct	1.46	0.11	1.13	0.07	0.33	0.10	507
2017 Jan	1.68	0.11	1.38	0.08	0.30	0.09	504
2017 Apr	1.80	0.10	1.61	0.08	0.19	0.08	504
2017 Jul	1.97	0.10	1.81	0.08	0.16	0.06	504
2017 Oct	2.06	0.10	1.93	0.09	0.13	0.07	505
2018 Jan	2.04	0.10	2.00	0.08	0.04	0.07	504
2018 Apr	1.94	0.17	2.01	0.10	−0.07	0.17	505
2018 Jul	1.74	0.26	1.80	0.10	−0.06	0.26	503
2018 Oct	1.49	0.21	1.56	0.10	−0.07	0.20	501
2019 Jan	1.27	0.16	1.28	0.10	−0.01	0.16	501
2019 Apr	0.99	0.18	0.99	0.09	0.00	0.18	503
2019 Jul	0.80	0.20	0.69	0.08	0.11	0.19	503
2019 Oct	0.61	0.20	0.43	0.07	0.17	0.21	501
2020 Jan	0.26	0.21	0.25	0.06	0.02	0.22	500
2020 Apr	0.23	0.04	0.08	0.03	0.15	0.05	501
2020 Jul	0.35	0.07	0.17	0.05	0.18	0.07	500
2020 Oct	0.73	0.13	0.45	0.08	0.28	0.12	501
2021 Jan	1.34	0.17	1.02	0.14	0.32	0.12	475
2021 Apr	1.85	0.21	1.51	0.17	0.34	0.17	500
Average	1.01	0.128	0.86	0.07	0.15	0.120	501

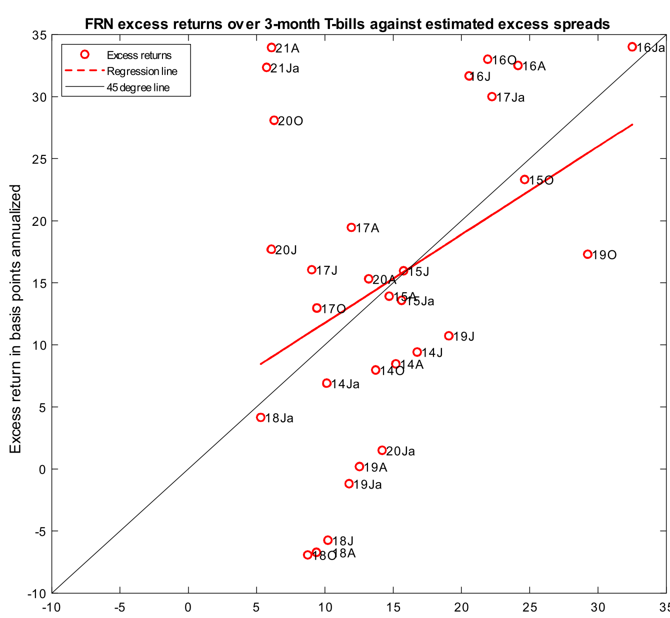

Fig. 7. FRN excess returns are daily average annualized returns over the life of an issue, including FRNs issued between 2014 and 2021 H1. Excess spreads are for new FRN issues. Text labels correspond to issue dates at the end of the months, with "Ja" = "January", "A" = "April", "J" = "July" and "O" = "October".

Overnight LIBOR. They also document excess returns for FRN issues relative to the T-bill index for the FRNs. Our excess returns of FRNs are with respect to the returns of T-bill investment strategies and are therefore not equivalent to the excess returns they compute.

5. Replication strategy with swaps

Fleckenstein and Longstaff (2020) compute replicating portfolios for Treasury FRNs using interest rate swaps together with T-bill/LIBOR basis swaps. They identify a price premium for Treasury FRNs relative to the replicating portfolios. Their finding implies that Treasury FRNs spreads have been excessively low relative the implied spreads of the replicating portfolios. We revisit their replication. In line with their analysis, we find that spreads for FRNs at auction dates have on average been lower than spreads of a replicating portfolio with swaps. However, the interpretation of this finding is challenging. While the apparent arbitrage could be due to an investor preference for Treasury FRNs relative to other Treasury securities, it could also be due to issues associated with the swap quotes used for the replication. As we document below, the T-bill/LIBOR basis swaps used in the replication portfolio have been extremely illiquid since the Global Financial Crises 2008-2009. In addition, it has been widely documented that since 2008 the pricing of interest rate swaps relative to Treasuries has been inconsistent with arbitrage principles, as fixed swap rates have often been lower than Treasury rates of the same maturity. Based on these facts, it is doubtful that apparent arbitrages computed with quotes of these swaps can be very informative about the properties of Treasury FRNs relative to other Treasury securities.

Fleckenstein and Longstaff (2020) compute a replication portfolio for a two-year Treasury FRN as an investment in a two-year fixed-rate Treasury note together with two swaps. First, the investor enters a standard interest rate swap paying the fixed swap rate in exchange for LIBOR. Second, the investor enters a basis swap paying LIBOR in exchange for receiving a T-bill index plus a fixed spread. The T-bill index of these swaps is very similar to the one used in Treasury FRNs. The result of the replication is a note with a floating T-bill index plus a spread that has two components: the T-bill basis swap spread plus the negative of the 2-year swap/Treasury spread. We have downloaded quotes for these two from Refinitiv Eikon and combined them in this way. This replication is imperfect in that the fixed rate Treasury coupons and the swap fixed payments are biannual while the FRN coupons are paid quarterly. We correct the spread by converting biannual payments into equivalent quarterly payments based on Treasury yield curves; this adjustment is immaterially small. We compute these replication spreads for FRN new auction dates and compare them to the spreads on the actual Treasury FRNs. This allows us to define an excess spread for the Treasury FRNs with respect to this replication spread that is directly comparable to our excess spreads computed based on the Treasury term structure.

Fig. 8 compares the two excess spreads. Consistent with the results highlighted by Fleckenstein and Longstaff (2020), the excess spreads for the swap replication have on average been negative. The average for the presented auction dates is −3 bps (−7 bps for the FRNs included in their sample which only goes to January 2020). That is, the cash flows from this replicating portfolios have exceeded on average the cash flows from the Treasury FRNs. They interpret this apparent failure of arbitrage as evidence that Treasury FRNs offer additional convenience relative to the other Treasuries. To rule out that their finding is driven by mispriced T-bill basis swaps, they present an example applying their replication approach to a set of floating rate/fixed rate note pairs from the Federal Farm Credit Bank. However, as it is clear from Table 8A in their online appendix, the sample period covered by this example is only about a third of their main sample period 2014-2018, covering mostly just 2017. As can be seen in Fig. 8, 2017 was an unusual year (this is consistent with the evidence in Figure 1 of their paper).

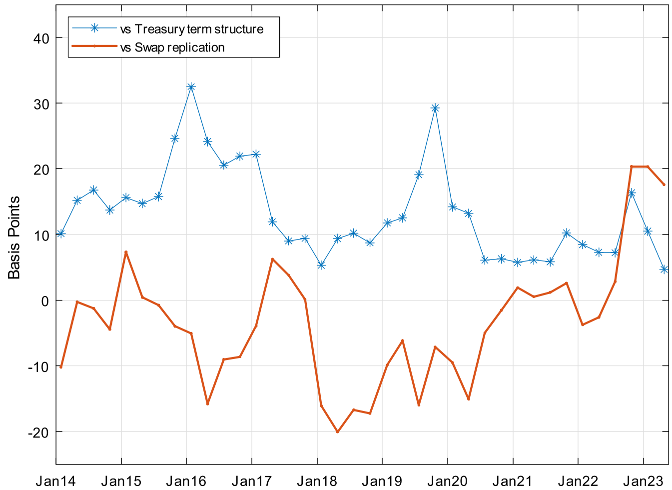

Fig. 8. FRN Excess Spreads relative to Treasury term structure and swap replication at auction dates of new Treasury FRNs.

Table 3
Swap data repository complete list of T-bill/LIBOR basis swaps executed 2013 to November 2021. Source: Clarus Financial Technology.

EXECUTION DATE	NOTIONAL	TENOR	PRICE
2/15/2013	10,000,000	165M	0.55
12/11/2013	200,000,000	2Y	
12/13/2013	50,000,000	20Y	0.82
5/23/2014	50,000,000	15Y	0.34
5/23/2014	50,000,000	15Y	0.34
6/23/2014	150,000,000	5Y	
9/12/2014	150,000,000	3Y	0.37
9/19/2014	150,000,000	3Y	0.33
9/25/2014	150,000,000	3Y	0.34
7/24/2015	45,000,000	20Y	0.40
9/25/2015	25,000,000	10Y	0.38
12/7/2015	100,000,000	3Y	0.34
5/16/2016	10,000,000	10Y	0.47
1/24/2018	100,000,000	2Y	
10/25/2018	50,000,000	5Y	0.77
12/13/2019	25,000,0000	207M	0.65

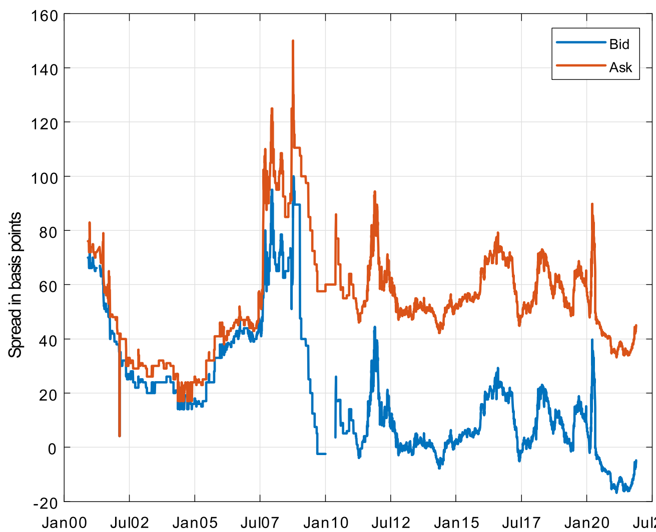

Fig. 9. T-bill/LIBOR basis swaps bid-ask quotes. 2-year maturity; Bloomberg.

We find T-bill/LIBOR basis swaps have been extremely illiquid since the global financial crisis of 2008. Bid-ask quoted spreads on Bloomberg and Refinitiv Eikon have widened to 50 bps (Fig. 9). The bid-ask prices are primarily broker quotes (provided by brokers like Tullett Prebon).

We have also more directly examined the liquidity of T-bill/LIBOR basis swaps. In recent years, data on all swaps traded by U.S. counterparties has become publicly available through swap data repositories ("SDRs"), new entities that were created by the Dodd-Frank Act of 2010 to provide a central facility for swap data reporting and recordkeeping. Under the Dodd-Frank Act, all swaps, whether cleared or uncleared, are required to be reported to registered SDRs.

We have obtained data from Clarus Financial Technology – a data firm that aggregates swap data repository data – for all T-bill/LIBOR basis swaps traded by U.S. counterparties. From 2013 to 2021, there were only 16 T-bill/LIBOR basis swaps trades. Only 1 of these with a maturity of 2 years or less has traded since 2014, when Treasury FRNs were first issued. This would be the only contract traded where the maturity could have matched a Treasury FRN which initially has a 2 year maturity. See Table 3. This lack of trading and the wide bid-ask rates quoted make it doubtful that apparent arbitrages computed with these quotes are informative about Treasury FRN prices. On the other hand, the absence of liquid hedging tools that would allow investors to eliminate mispricing in Treasury FRNs may be in part responsible for the mispricing we have documented earlier in the paper.

To dig deeper into the drivers of the FRN spread implied by the replication with swaps, Fig. 10 plots the swap/Treasury 2-year spreads and the T-bill/LIBOR basis swap quoted spreads. As an example, consider the FRN auction of January 28, 2020. The auction determined a FRN spread of 15.4 bps. On that date, the 2-year swap/Treasury spread was 3.65 bps and the T-bill basis swap midpoint quote 28.55 bps. The replication spread is therefore very close to $28.55 - 3.65 = 24.9$ bps. Based on this, the actual FRN spread was below the replication spread by about $15.4 - 24.9 = -9.5$ bps.[4] Clearly, a low swap/Treasury spread increases the replication spread so that the actual FRN spread appears relatively low. Negative swap/Treasury spreads for 30-year swaps have been widely documented and the implied failure of no-arbitrage pricing has been widely recognized in the literature.[5] While such negative swap spreads for the shorter maturities have been less common, as shown in Fig. 10, even the 2-year swap spreads have occasionally been negative. It seems very natural to conclude from this that 2-year swap/Treasury spreads have been "too low" relative to frictionless no-arbitrage pricing and that this distortion can lead to FRN replication spreads that are "too high", which could be an explanation for the findings in Fleckenstein and Longstaff (2020).

6. Interpretation of excess spreads

This section presents a dynamic pricing model that offers an interpretation for the failure of the Law of One Price associated with Treasury FRNs. In addition to cash flows, securities can provide other service flows to investors and these can be priced as convenience yields. Treasuries have long been viewed as offering such convenience yields. See for instance, Krishnamurthy and Vissing-Jorgensen (2012) or Greenwood et al. (2015); more recently Treasuries have also experienced episodes characterized by inconvenience yields, suggesting a rich set of priced attributes, He et al. (2022) and Klingler and Sundaresan (2023). From this perspective, our findings that FRNs have offered excess spreads and higher returns than T-bills imply that the service flows

[4] The exact excess spread that includes the adjustment due to Treasury and swaps paying coupons bi-annually and FRNs quarterly is -9.5067 bps.

[5] See, for instance, Augustin et al. (2021), Boyarchenko et al. (2018), Jermann (2020), Du et al. (2023), and Hanson et al. (2024).

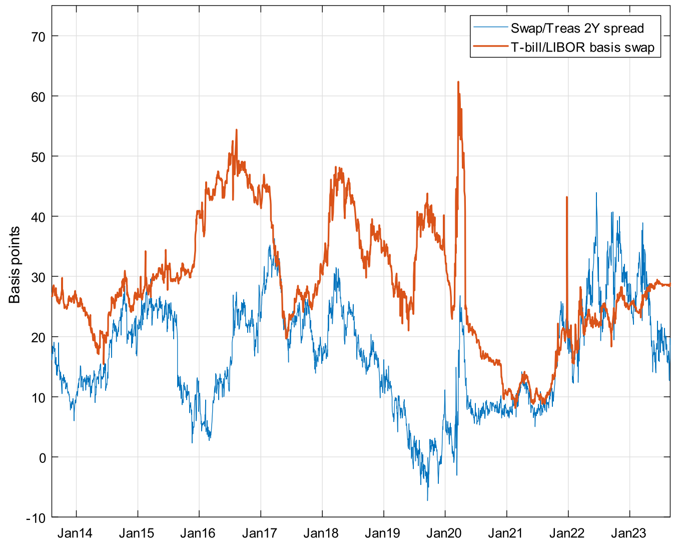

Fig. 10. Swap/Treasury 2-year spreads and T-bill/LIBOR basis swap quotes; Refinitiv Eikon.

provided by FRNs are relatively less valuable than those from T-bills. We first present a framework that formalizes these ideas. Guided by this framework, we then examine the relation between the documented excess spreads and potential explanatory factors.

6.1. Infinite-horizon model with convenience yields

Assume that near-money assets have different degrees of moneyness and are appreciated by investors for different properties. We consider a discrete-time infinite-horizon environment, and we focus on investors first-order conditions and the implied equilibrium prices for select securities.

T-bills purchased at time t are assumed to mature next period and become cash. Cash provides some service flows that give utility to investors. The investors' first-order condition for a T-bill is

$$p_t = \beta E_t \frac{\Lambda^1_{t+1}}{\Lambda_t},$$

where Λ_t is the marginal utility of consumption (or wealth) and Λ^1_{t+1} the marginal utility of consumption in addition to the service flows associate with having cash next period, β is a discount parameter.

We represent FRNs as multiperiod bonds with geometric amortization. A bullet bond has a large utility value in the last period for the principal. This would complicate the algebra, but without any substantive impact on our arguments. For a geometrically amortizing FRN, next period's coupon and amortization payments are considered to be cash-like. Under these assumptions, a newly issued FRN with spread s is priced as

$$q_t = \beta E_t \frac{\Lambda^1_{t+1}}{\Lambda_t}\left[\iota_{t+1} + s + \lambda\right] + \beta E_t \frac{\Lambda^2_{t+1}}{\Lambda_t}(1-\lambda)\, q_{t+1}. \tag{6}$$

Next period's interest including the spread $\left(\iota_{t+1} + s\right)$ as well as the amortization, $0 < \lambda < 1$, are cash-like and therefore valued with Λ^1_{t+1} like maturing T-bills. The marginal valuation of the non-amortized portion, Λ^2_{t+1}, includes the marginal utility of consumption in addition to the services flows specific to the FRN. This can include price stability and convenience for savers. This preference for stability goes beyond the usual aversion to price risk implied by a concave utility function for consumption. For instance, stable-valued assets are good collateral and are relatively easier to borrow and settle. T-bills are also stable-valued, so that typically one can expect $\Lambda^1_{t+1} > \Lambda^2_{t+1}$. However, FRNs have some specific convenience for savers, such as not requiring to be rolled over every period, which is not shared by T-bills. Therefore, the difference between these two marginal valuations can fluctuate. Appendix B shows how these first-order conditions can be derived from an extended version of a money-in-the-utility-function specification building on ideas from Sidrauski (1967) or Feenstra (1986); allowing for different sources of moneyness among near-money like assets is in line with more recent studies such as, for instance, Krishnamurthy and Vissing-Jorgensen (2012).[6]

The coupon index of the FRN is given by the T-bill rate,

$$\iota_{t+1} = 1/p_t - 1 \equiv i^1_t, \tag{7}$$

where i^1_t is the one-period T-bill rate between t and $t+1$. Just to be clear, in this model we abstract from the complication due to the constant maturity index. This should mostly affect very high frequency properties.

The spread of a newly issued FRN at t, s_t, is determined by setting $q_t = 1$. Substituting (7) in (6) and iterating forward (see Appendix B) this becomes

$$s_t = (1-\lambda)\frac{\Phi_t\left(\left\{\kappa_t\right\}\right)}{\Phi_t\left(\{1\}\right)}, \tag{8}$$

with the annuity operator

$$\Phi_t\left(\left\{x_t\right\}\right) \equiv \sum_{k=0}(1-\lambda)^k \beta^{1+k} E_t \frac{\Lambda^1_{t+1+k}}{\Lambda_t}\prod_{l=1}^{k}\frac{\Lambda^2_{t+l}}{\Lambda_{t+l}} x_{t+k}.$$

And

$$\begin{aligned}
\kappa_{t+k} &\equiv 1 - E_t \frac{\Lambda^2_{t+1+k}}{\Lambda_t}\prod_{l=1}^{k}\frac{\Lambda^2_{t+l}}{\Lambda_{t+l}} \Big/ E_t \frac{\Lambda^1_{t+1+k}}{\Lambda_t}\prod_{l=1}^{k}\frac{\Lambda^2_{t+l}}{\Lambda_{t+l}} \\
&= E_t \prod_{l=1}^{k}\frac{\Lambda^2_{t+l}}{\Lambda_{t+l-1}}\left(\frac{i^2_{t+k} - i^1_{t+k}}{\left(1+i^1_{t+k}\right)\left(1+i^2_{t+k}\right)}\right) \Big/ E_t \prod_{l=1}^{k}\frac{\Lambda^2_{t+l}}{\Lambda_{t+l-1}}\left(\frac{1}{1+i^1_{t+k}}\right) \\
&\approx E_t\left\{\prod_{l=1}^{k}\frac{\Lambda^2_{t+l}}{\Lambda_{t+l-1}} \Big/ E_t \prod_{l=1}^{k}\frac{\Lambda^2_{t+l}}{\Lambda_{t+l-1}}\right\}\left(i^2_{t+k} - i^1_{t+k}\right) \\
&\approx E_t^{Q_2(k)}\left(i^2_{t+k} - i^1_{t+k}\right)
\end{aligned} \tag{9}$$

with the one-period rate implied by the marginal valuation used for outstanding FRNs given as

$$\frac{1}{1+i^2_{t+k}} = \beta E_{t+k}\frac{\Lambda^2_{t+k+1}}{\Lambda_{t+k}}.$$

As shown in Equation (9), κ_{t+k} can be viewed as measuring the moneyness spread of FRNs relative to T-bills at different horizons k. Specifically, it is the expected spread of the one-period rate implied by the valuation for FRNs relative to the one-period T-bill rate i^1_{t+k}. As discussed above, we expect typically that $\Lambda^1_{t+1} > \Lambda^2_{t+1}$ because T-bills have the most important money-like properties and only lack the FRNs' convenience of not requiring to be rolled over by savers every period. The FRN moneyness spread is then typically positive, $\left(i^2_{t+k} - i^1_{t+k}\right) > 0$, implying that the FRNs spread s_t is positive. Clearly, in a standard no-arbitrage setting without special utility for money-like assets, s_t equals 0. Therefore the spread s_t can be viewed as the counterpart of the empirical excess spreads we have documented.

In a steady state with constant one-period rates we have

$$s = (1-\lambda)\left(\frac{i^2 - i^1}{1+i^2}\right). \tag{10}$$

[6] The model could be extended to allow for balance sheet constraints which can negatively impact valuations. See for instance, Jermann (2020) or He et al. (2022).

Table 4
Regression of excess spreads in FRNs 1/2014 - 06/2023. All variables are measured at FRN auction dates. Regressions are estimated with a constant by OLS with Newey-West standard errors. The marginal adjusted R-square is the R-square with all regressors minus the R-square with this regressor removed. Interest rate volatility is measured by the MOVE6M index.

Regressor	Coefficient	p-value	Marginal Adj. R-square
OIS - T-bill spread	−0.48	< 0.001	0.34
LIBOR - T-bill spread	0.12	0.001	0.08
Interest rate volatility	0.14	.008	0.09
3-month T-bill	−2.8	< 0.001	0.18
Adj. R-square	0.50		
N-obs	114		

Intuitively, investors in a multi-period FRN need to be compensated for the non-amortized component $(1-\lambda)$ which has a lower degree of moneyness than T-bills.

6.2. Factors correlated with excess spreads

Based on Equation (8) and (9), we empirically examine factors that have the potential to capture the mechanisms highlighted by the model. Spreads of non-government short rates such as OIS and LIBOR relative to T-bill rates have been widely used as measures of monetary convenience yields. Cash is presumably more highly valued during periods of high uncertainty, which leads us to consider a measure of interest rate volatility. Finally, being a convenient tool for savers is presumably more appreciated when money-like assets pay a higher return. For that reason, we include the level of the short rate as well.[7]

The OIS minus T-bill spread is based on the 3-month forward rates averaged across starting months $0, 3, 6, \ldots$ up to 21. The LIBOR minus T-bill spread is the average based on the 3-month forward rates starting at months $0, 3, 6$, and 9. This corresponds to the (spot) TED spread averaged with forward TED spreads. Interest rate volatility is measured by the MOVE6M index that represents 6-month option implied volatilities of Treasury securities. As the short rate, we use the 3-month T-bill rate.

Table 4 shows all the included regressors entering with high statistical significance generating an adjusted R-square of 0.50. When focusing on the marginal R-square from each regressor separately, all make non-neglible contributions. The signs are as expected, except possibly for the OIS - T-bill spread. The negative coefficient suggests that when short-term Treasuries provide low convenience, the convenience of Treasury FRNs is even lower.[8] The OIS - T-bill spread makes a particularly strong contribution to the R-square. Using the entire range of OIS - T-bill spreads, as the model suggests, is important. If instead the regressions are run with the spot 3-month OIS - T-bill spread, its marginal R-square goes essentially to zero.

Fig. 11 plots FRN excess spreads with each regressor individually. For the first three panels, comovements at medium and higher frequencies are evident. In the last panel, the 3-month T-bill rate displays primarily low frequency movements. The large increase at the end of the sample is helpful in counteracting the large increase in the MOVE indicator of interest volatility.

[7] Retail ETFs for FRNs such as USFR and TFLO have been around since 2014. However, fund assets have been relatively low until recently. From January 2022 to October 2023 total net assets increased from 1,870 to 18,750 mn$ for USFR, and from 352 to 10,796 mn$ for TFLO, as reported by Refinitive Eikon. These increases coincide with the sharp increase in short-term interest rates.

[8] Klingler and Sundaresan (2023) show that since 2015 the OIS - T-bill spread behaves contrary to the more traditional safe haven indicator, except when VIX has been very elevated. They attribute this to primary dealer balance sheet constraints.

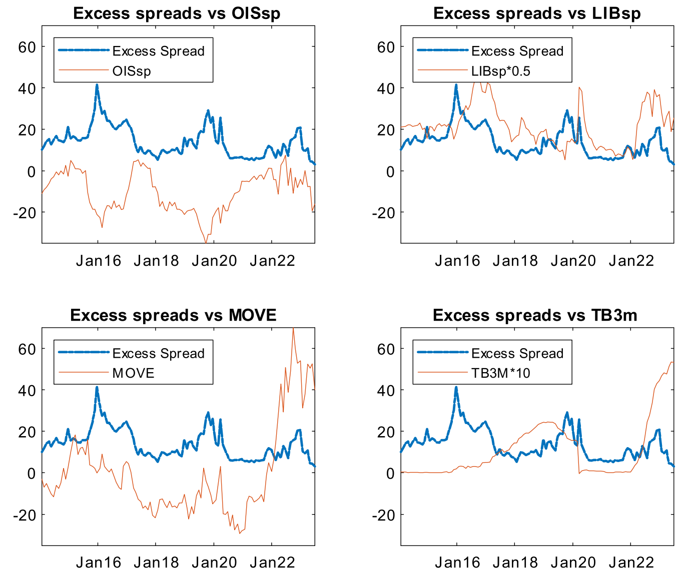

Fig. 11. FRN excess spreads vs regressors. For better visualization, the LIBOR - T-bill spread is scaled by 0.5, MOVE is demeaned, and the 3-month T-bill rate (TB3m) is scaled by 10.

6.3. Excess spreads by remaining maturity

The analysis of this paper has focused on pricing spreads at FRN auctions with maturities of 24 months for new auctions and 23 or 22 months for reopening auctions. In this section, we consider excess spreads for shorter maturities based on secondary market prices. Consistent with the long-run behavior implied by the model presented in Subsection 6.1, we find that FRNs with shorter maturities have had mostly monotonically smaller excess spreads. Starting in 2022, the relationship between maturity and excess spreads has been more random.

The steady-state characterization of the spread in Equation (10) implies a positive relation between the maturity, $1/\lambda$, and the absolute value of the spread, s. To be clear, the maturity of a geometrically amortizing bond does not decline over time. But one can interpret FRNs with different outstanding maturities as bonds with different $\lambda's$. Considering a bullet bond within the setting of the model, the share of its value due to the next coupon – which is the most money-like – increases as the maturity declines, and this is associated with a tighter spread. Based on the model, one would therefore predict the remaining maturity and FRNs excess spreads to be positively correlated.

We have computed excess spreads at quarterly maturity intervals for all new auction dates. The calculation is based on Equation (1), with the price V_0 set to the secondary market mid-point close price of each date. Fig. 12 displays the times series of the excess spreads with maturities ranging from two years to three months. Between 2014 and 2022 excess spreads have been mostly monotonic in maturity, and except for the 3-month notes, excess spreads were always positive. Starting in 2022, excess spreads were no longer monotonic, and for some of the shorter maturities there have been some negative values, particularly in early 2023. As shown in Fig. 11, starting in 2022, interest rate volatility has sharply increased, and short term interest rates have increased. In addition, bid-ask spreads for secondary market prices of FRNs as implied by quotes from Refinitiv Eikon have widened dramatically in 2022 and 2023. Prior to 2022, reported bid-ask spreads were mostly far less than 5 bps and declining towards zero in maturity, with the exception of a short period around March 2020. In 2022 and 2023 bid-ask spread have widened to above 15bps at times even for shorter maturities. See Appendix C for more details.

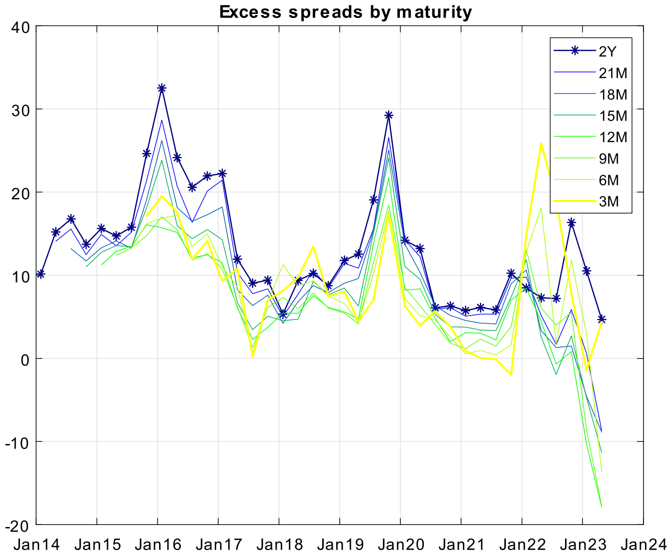

Fig. 12. Excess spreads at new FRN auction dates. Excess spreads for maturities of 21 months and less are based on secondary market prices.

7. Conclusion

The FRNs issued by the U.S. Treasury since 2014 pay interest based on a constant maturity index of T-bill rates. This feature requires an explicit pricing model. We have derived a no-arbitrage pricing model for this purpose and shown that an accurate approximation for pricing FRNs can be based on implied forward rates alone. Convexity adjustments have increased recently, but they continue to be quantitatively unimportant.

Our main finding is that U.S. Treasury FRNs when priced through a no-arbitrage approach have been paying excessively high interest. The excess spreads paid by these FRNs have fluctuated over time but have been uniformly positive at all auctions. We interpret this excess spread as evidence that the liquidity services provided by FRNs have been less valuable than those of other short-term Treasury securities such as T-bills. Separate regression results confirm this interpretation. It is an open question whether the additional interest the Treasury has been paying represents an adequate compensation for the reduction in the risks associated with rolling over short-term debt, which has been one of stated objectives for issuing these FRNs.

CRediT authorship contribution statement

Jonathan S. Hartley: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. **Urban J. Jermann:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing, Resources.

Declaration of competing interest

None.

Data availability

The code and data of the article can be found at https://data.mendeley.com/datasets/w7tv9bxwy3/1.

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Appendix A. Pricing FRNs

The main pricing equation is derived for a four period environment with periods $t = 0, 1, 2, 3$. This reduces notational complexity.

At time $t = 0$, we price a claim that pays a single coupon at time $t = 2$. This coupon is defined as

$$C_2 = \frac{1}{2}\left(r_{0,2} + r_{1,3}\right),$$

that is, the average of the two-period rates determined at time $t = 0$ and $t = 1$. Clearly, as of time $t = 0$, $r_{1,3}$ is not known. Like the Treasury FRNs, this note pays a coupon that is an average of constant-maturity rates.

Ruling out arbitrage, there exists a state-price valuation process Λ_t that determines the price of this claim

$$V_0 = E_0\left[\frac{\Lambda_2}{\Lambda_0} C_2\right] = E_0\left[\frac{\Lambda_2}{\Lambda_0}\frac{\left(r_{0,2} + r_{1,3}\right)}{2}\right]$$

$$= \frac{r_{0,2}}{2} E_0\left[\frac{\Lambda_2}{\Lambda_0}\right] + \frac{1}{2} E_0\left[\frac{\Lambda_2}{\Lambda_0} r_{1,3}\right],$$

and

$$V_0 = \frac{1}{2}\frac{r_{0,2}}{1 + r_{0,2}} + \frac{1}{2} E_0\left[\frac{\Lambda_2}{\Lambda_0} r_{1,3}\right]. \tag{11}$$

Pricing the second strip is nontrivial in that is not just a function of the current (time 0) term structure. Specifically, because there is a timing mismatch between the payment date, 2, and the maturity date implied by the rate used, 3, current forward rates and the current term structure are in general not enough for pricing the second strip. This applies to all the strips of the Treasury FRNs with rates determined between 1 and 12 weeks after the beginning of a quarter.

Derivation of the pricing equation

The second term in Equation (11)

$$E_0\left[\frac{\Lambda_2}{\Lambda_0} r_{1,3}\right] = E_0\frac{\Lambda_2}{\Lambda_0} E_0\left(r_{1,3}\right) + Cov_0\left(\frac{\Lambda_2}{\Lambda_0}, r_{1,3}\right)$$

$$= \frac{E_0\left(r_{1,3}\right)}{1 + r_{0,2}} + Cov_0\left(\frac{\Lambda_2}{\Lambda_0}, r_{1,3}\right). \tag{12}$$

Ruling out arbitrage implies that

$$1 = \left(1 + r_{0,1}\right) E_0\left[\frac{\Lambda_3}{\Lambda_0}\left(1 + r_{1,3}\right)\right]$$

and multiplying both sides by $\left(1 + r_{0,3}\right) = 1/E_0\frac{\Lambda_3}{\Lambda_0}$

$$\frac{1 + r_{0,3}}{1 + r_{0,1}} = E_0\left[\left\{\frac{\Lambda_3}{\Lambda_0}/E_0\left(\frac{\Lambda_3}{\Lambda_0}\right)\right\}\left(1 + r_{1,3}\right)\right] \equiv \left(1 + r^f_{0,1,3}\right).$$

This shows the forward rate as the expected value of the future spot rate $r_{1,3}$ with the normalized discount rate $\left\{\frac{\Lambda_3}{\Lambda_0}/E_0\left(\frac{\Lambda_3}{\Lambda_0}\right)\right\}$. Rewriting the last two terms as

$$\left(1+r^f_{0,1,3}\right)=E_0\left(1+r_{1,3}\right)+Cov_0\left(\frac{\Lambda_3}{\Lambda_0}/E_0\left(\frac{\Lambda_3}{\Lambda_0}\right),r_{1,3}\right)$$

links the forward rate and the expected future spot rate. Substituting $E_0\left(r_{1,3}\right)$ in Equation (12)

$$\begin{aligned}
E_0\left[\frac{\Lambda_2}{\Lambda_0}r_{1,3}\right] &= \frac{r^f_{0,1,3}-Cov_0\left(\frac{\Lambda_3}{\Lambda_0}/E_0\left(\frac{\Lambda_3}{\Lambda_0}\right),r_{1,3}\right)}{1+r_{0,2}}+Cov_0\left(\frac{\Lambda_2}{\Lambda_0},r_{1,3}\right)\\
&= \frac{r^f_{0,1,3}}{1+r_{0,2}}+Cov_0\left(\frac{\Lambda_2}{\Lambda_0}-\frac{\frac{\Lambda_3}{\Lambda_0}/E_0\left(\frac{\Lambda_3}{\Lambda_0}\right)}{1+r_{0,2}},r_{1,3}\right)\\
&= \frac{r^f_{0,1,3}}{1+r_{0,2}}+Cov_0\left(E_1\frac{\Lambda_2}{\Lambda_0}-\frac{E_1\frac{\Lambda_3}{\Lambda_0}/E_0\left(\frac{\Lambda_3}{\Lambda_0}\right)}{1+r_{0,2}},r_{1,3}\right)\\
&= \frac{r^f_{0,1,3}}{1+r_{0,2}}+Cov_0\left(\frac{1}{1+r_{1,2}}\frac{\Lambda_1}{\Lambda_0}-\frac{\frac{\Lambda_1}{\Lambda_0}\frac{1}{1+r_{1,3}}/E_0\left(\frac{\Lambda_3}{\Lambda_0}\right)}{1+r_{0,2}},r_{1,3}\right)\\
&= \frac{r^f_{0,1,3}}{1+r_{0,2}}+Cov_0\left(\frac{\Lambda_1}{\Lambda_0}\frac{1}{1+r_{1,3}}\left[\frac{1+r_{1,3}}{1+r_{1,2}}-\left(1+^f_{0,2,3}\right)\right],r_{1,3}\right)\\
&= \frac{r^f_{0,1,3}}{1+r_{0,2}}+Cov_0\left(\frac{\Lambda_1}{\Lambda_0}\frac{1}{1+r_{1,3}}\left[r^f_{1,2,3}-r^f_{0,2,3}\right],r_{1,3}\right)
\end{aligned}$$

This shows the price as a term based on the forward rate and a “convexity adjustment”, the covariance. This corresponds to Equation (4) in the main text.

Risk-neutral expectations and interest rate volatility
Introducing the definition of risk-neutral expectations, E^Q_0,

$$\begin{aligned}
E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0}r^{13}_{I+k}\right] &= E_0\left[\frac{\Lambda_{I+k}}{\Lambda_0}\frac{\Lambda_{I+13}}{\Lambda_{I+k}}r^{13}_{I+k}\right]=E_0\left[\frac{\Lambda_{I+k}}{\Lambda_0}\frac{r^{13}_{I+k}}{1+r^{13-k}_{I+k}}\right]\\
&= E_0\left\{\frac{\Lambda_{I+k}}{\Lambda_0}\right\}E_0\left[\frac{\Lambda_{I+k}}{\Lambda_0}/E_0\left\{\frac{\Lambda_{I+k}}{\Lambda_0}\right\}\frac{r^{13}_{I+k}}{1+r^{13-k}_{I+k}}\right]\\
&= \frac{1}{1+r^{I+k}_0}E^{Q(I+k)}_0\left[\frac{r^{13}_{I+k}}{1+r^{13-k}_{I+k}}\right].
\end{aligned}$$

Rewrite the expectation of the product as

$$\begin{aligned}
E_0\left[\frac{\Lambda_{I+13}}{\Lambda_0}r^{13}_{I+k}\right] &= \frac{1}{1+r^{I+k}_0}E^{Q(I+k)}_0\left[\frac{r^{13}_{I+k}}{1+r^{13-k}_{I+k}}\right]\\
&= \frac{1}{1+r^{I+k}_0}\left\{E^{Q(I+k)}_0\left[\frac{1}{1+r^{13-k}_{I+k}}\right]E^{Q(I+k)}_0\left[r^{13}_{I+k}\right]\right.\\
&\quad\left.+Cov^{Q(I+k)}_0\left(\frac{1}{1+r^{13-k}_{I+k}},r^{13}_{I+k}\right)\right\}\\
&= \frac{1}{1+r^{I+k}_0}\left[V^{f,13-k}_{0,I+k}\right]E^{Q(I+k)}_0\left[r^{13}_{I+k}\right]\\
&\quad+\frac{1}{1+r^{I+k}_0}Cov^{Q(I+k)}_0\left(\frac{1}{1+r^{13-k}_{I+k}},r^{13}_{I+k}\right)\\
&= \frac{E^{Q(I+k)}_0\left[r^{13}_{I+k}\right]}{1+r^{I+13}_0}\\
&\quad+\frac{1}{1+r^{I+k}_0}Cov^{Q(I+k)}_0\left(\frac{1}{1+r^{13-k}_{I+k}},r^{13}_{I+k}\right).
\end{aligned}$$

The numerator of the first term can be rewritten as

$$E^{Q(I+k)}_0\left[r^{13}_{I+k}\right]=E^{Q(I+k)}_0\left[\frac{1}{V^{13}_{I+k}}\right]-1,$$

where V^{13}_{I+k} is the price at time $I+k$ of a zero-coupon bond that matures at $I+k+13$. Note that a second-order Taylor approximation of $E(1/x)$ around $x=E(x)$ yields

$$E\left(\frac{1}{x}\right)\cong\frac{1}{E(x)}\left[1+\frac{Var(x)}{E^2(x)}\right],$$

and that

$$E^{Q(I+k)}_0\left[V^{13}_{I+k}\right]=\frac{E_0\left[\frac{\Lambda_{I+k}}{\Lambda_0}V^{13}_{I+k}\right]}{E_0\frac{\Lambda_{I+k}}{\Lambda_0}}=\frac{V^{I+k+13}_0}{V^{I+k}_0}=\frac{1}{1+r^{f,13}_{0,I+k}},$$

so that combined

$$E^{Q(I+k)}_0\left[\frac{1}{V^{13}_{I+k}}\right]\cong\left(1+r^{f,13}_{0,I+k}\right)\left[1+\left(1+r^{f,13}_{0,I+k}\right)^2Var_0\left(\frac{1}{1+r^{13}_{I+k}}\right)\right].$$

Using this expression to substitute out $E^{Q(I+k)}_0\left[r^{13}_{I+k}\right]$ gives Equation (5) in the main text.

Appendix B. Pricing FRNs with money-in-the-utility

Assume investors have time-separable utility for consumption, C_t, and for the money-like properties of securities. Period utility is given as

$$u\left(C_t\right)+v_t\left(L_t\right)+w_t\left(S_t\right)+z_t\left(N_t\right)$$

where $v_t(.)$, $w_t(.)$, and $z_t(.)$ are the utilities for different properties. They can be state-contingent as indicated by the time-subscript. Utility is provided by three properties: liquidity, stability and convenience for savers, denoted by L, S and N. Cash is assumed to contribute to L and S. FRNs are assumed to contribute to S and N. The contributions are additive. Under these assumptions the marginal valuations used in the pricing equation in the main text are given by

$$\Lambda_t=u'\left(C_t\right),$$

$$\Lambda^1_{t+1}=u'\left(C_{t+1}\right)+v'_{t+1}\left(L_{t+1}\right)+w'_{t+1}\left(S_{t+1}\right),\text{ and}$$

$$\Lambda^2_{t+1}=u'\left(C_{t+1}\right)+w'_{t+1}\left(S_{t+1}\right)+z'_{t+1}\left(N_{t+1}\right),$$

where a prime indicates a derivative.

The first-order condition for a FRN

$$q_t=\beta E_t\frac{\Lambda^1_{t+1}}{\Lambda_t}\left[\iota_{t+1}+s+\lambda\right]+\beta E_t\frac{\Lambda^2_{t+1}}{\Lambda_t}(1-\lambda)q_{t+1}$$

combined with definition of the coupon, ι_{t+1}, becomes

$$q_t=1+(s+\lambda-1)\beta E_t\frac{\Lambda^1_{t+1}}{\Lambda_t}+\beta E_t\frac{\Lambda^2_{t+1}}{\Lambda_t}(1-\lambda)q_{t+1},$$

which is iterated forward to produce Equations (8) and (9) presented in the main text.

Appendix C. Bid-ask spreads FRNs secondary market (Fig. 13)

Fig. 13. Bid-ask spreads for FRNs as a % of the mid-price. Data source: Refinitiv Eikon.

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