New Evidence on Convenient Asset Demand

Collin Jones
UC Berkeley

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Abstract

This paper studies aggregate demand for short-term convenient assets. I estimate the slope of the aggregate demand curve for these assets, which governs how a given change in convenient assets outstanding changes their convenience yield. I innovate relative to the existing literature by using a new instrument, which is a direct measure of T-bill issuance *surprises* relative to the projections of a well-informed market newsletter, Wrightson ICAP. I argue that Wrightson surprises are plausibly uncorrelated with changes in convenience demand, and are a methodological improvement over the literature's previous approaches. Using local projection methods, I find that the demand curve for short-term convenient assets is meaningfully steep only in the very short-run. A $100 billion increase in the supply of T-bills depresses T-bill convenience yields by 10.4 basis points, on average, in the week of the increase. However, the long-run effect is much more modest, with a $100 billion higher *stock* of T-bills only depressing convenience yields by 1.1 basis points.

1 Introduction

Investor demand for convenient, short term assets has come to occupy an important place in macroeconomic models across a variety of subdisciplines. In models of optimal fiscal policy and government financing, a desire to sate this demand means that governments should issue more debt that satisfies this special investor need. In business cycle models, fluctuations in the strength of this demand can drive business cycles, by shifting the desirability of savings in a way that is not reversed by central banks.

The quantitative predictions and policy prescriptions of these models are linked to the price sensitivity of this convenient asset demand. This is the *slope* of the convenient asset demand curve. In this context, the price of convenience is the difference in yield between some less convenient reference asset and a convenient asset. This difference is the convenience yield, and measures the yield that an investor will *forgo* by holding a convenient asset. A flat demand curve means that large increases in the outstanding supply of short-term convenient assets cause only modest decreases in this convenience yield. When this demand curve is flatter, the US government's debt issuance decisions are less likely to drive business cycles, as in Kekre and Lenel (2021), and a given fiscal deficit is more likely to be fiscally sustainable, as in Mian et al. (2022). In normative terms, a flatter convenient asset demand curve suggests to policymakers that maintaining a larger supply of these assets is good for welfare, all else equal.[1]

Several recent studies have estimated the slope of this demand curve, by observing how convenience yields have historically changed after changes in the outstanding quantity of convenient assets. Krishnamurthy and Vissing-Jorgensen (2012) does this with a long sample and low frequency variation in the outstanding quantity of Treasury securities. Greenwood et al. (2015b) does this using higher frequency variation in the outstanding quantity of short-term Treasury bills (T-bills).

As in any setting where the goal is to estimate the slope of a demand curve, identification relies on isolating a component of convenient asset supply that is uncorrelated with any unobservables that independently shift demand. In high frequency studies like Greenwood et al. (2015b), the most-discussed endogeneity concern is *opportunistic issuance*: that the Treasury may respond to movements in the price of convenience by changing their issuance of convenient debt.[2] Those authors address this using a seasonality instrument, arguing that the seasonality in outstanding T-bill supplies is driven by predetermined deadlines in the US tax calendar – *not* by a Treasury response to demand. This seasonality approach is still standard in this literature, used in studies as recent as D'Avernas and Vandeweyer

[1] Vissing-Jorgensen (2023) discusses this in the monetary policy context. Angeletos et al. (2023) discusses it in the fiscal context.

[2] To continue the analogy between this setting and a classic demand curve estimation problem: Opportunistic issuance would imply that the US Treasury's supply curve is not vertical. This induces a simultaneous equation estimation problem.

(2022) and Infante (2020).

In this paper, I estimate the slope of the short-term, convenient asset demand curve in the post-crisis period using a fundamentally different instrument. My instrument measures surprises in the quantity of T-bills sold by the Treasury at auction. I measure the size of these surprises directly, using high frequency projections of T-bill auction quantities from Wrightson, a highly-informed and well-respected money market newsletter. Using these surprises as an instrument for T-bill supply, I demonstrate that convenient asset demand appears rate insensitive (steep) in the very short run, but price sensitive (flat) at only slightly longer horizons. My results suggest that a $100 billion larger *stock* of T-bills depresses T-bill convenience yields by only 1.1 basis points. However, a $100 billion *increase* in the supply of T-bill will depress convenience yields by 10.4 basis points in the week of the change.

I argue that Wrightson surprises are plausibly uncorrelated with high frequency shifts in convenient asset demand, permitting their use as instruments to estimate the slope of the demand curve. The most important component of this argument is an institutional quirk in the Treasury's T-bill issuance strategy. To avoid being seen as an opportunistic issuer, the Treasury *does not* alter their issuance decisions in response to short-term changes in demand. Treasury statements to this effect are unambigious and speak directly to my exclusion restriction. In one slide deck displayed prominently on the US Treasury's website, the Office of Debt Management writes "Treasury doesn't react to current rate levels or short-term fluctuations in demand".[3] This suggest that when the Treasury surprises Wrightson by issuing more or fewer T-bills than expected, they are not doing so as a response to convenient asset demand. That is, high frequency surprises do not reflect opportunistic issuance.[4]

In some ways, my approach is similar to the methods employed by the high frequency identification (HFI) literature that identifies shocks as intraday price changes around policy announcements, but my setting necessitates an important difference. In that literature, the object of interest is typically an estimate of how a change in *prices* effected by some policy action affects other financial variables.[5] In this paper, I study how changes in some variable other than price (i.e. T-bill supply) affect prices and other financial variables. Measuring a change in prices at high frequencies (even if one believes the exclusion restriction that it reflects supply decisions of the Treasury alone, does not measure the size of the supply surprise that effected it.[6]

[3]This presentation, which I will discuss further in the main text of this paper, is available as of October 2023 at https://home.treasury.gov/system/files/276/Debt-Management-Overview.pdf.

[4]Importantly, these statements do not necessarily mean that T-bill issuance at lower frequencies is not opportunistic. In response to some persistent change in investor demand for convenient assets, the Treasury may gradually change its issuance strategy. My identification argument must be paired with a high frequency approach, to accord most closely with this stated Treasury policy.

[5]An excellent example is the monetary policy literature that relies on HFI methods, as in Nakamura and Steinsson (2018) and Kuttner (2001). Those papers study how changes in interest rates, plausibly caused by some monetary policy action, affect other variables at high frequencies.

[6]In a contemporaneous study that I see as complementary to this paper, Phillot (2021) studies how changes in futures prices for longer-term Treasury coupons and notes on supply announcement

An inherent complication in studying my research question relates to the supply of T-bill *substitutes*. If other assets provide convenience qualities that are substitutable with the convenience provided by T-bills, then the available quantity of those other assets will affect T-bill convenience yields in equilibrium. Even if the US Treasury does not alter its issuance in response to market rates, issuers of substitutable assets may. We might expect those issuers to decrease their issuance after a positive T-bill quantity surprise. This induces a sort of measurement problem. While Wrightson surprises are still a valid supply instrument under my exclusion restriction, observable changes in T-bill supply after a shock may not reflect the total change in relevant short-term convenient asset quantities.

I address this issue chiefly via a sample restriction, motivated by recent insights from D'Avernas and Vandeweyer (2022). Using a simple stylized framework, I clarify that this issue is most problematic in my post-crisis sample when the Federal Reserve's Overnight Reverse Repurchase Agreement (ONRRP) facility is active. In those weeks, the Fed's monetary policy tools make a portion of plausibly-substitutable convenient asset supply (i.e. repurchase agreements issued by the Fed) perfectly rate elastic, dampening the effect of T-bill supply shocks on rates. As such, in the analyses of convenience yields to follow, I exclude from my sample those weeks when the ONRRP facility is active.

Employing this sample restriction, I use Wrightson surprises as instruments to estimate the dynamic response of T-bill convenience yields to a T-bill supply shock, with a local projection instrumental variables (LP-IV) approach. These results show that defining the horizon of interest is hugely important for interpreting the magnitude of the convenience yield response. In the first weeks after a supply shock, T-bill convenience yields drop sharply. However, they recover quickly, with the point estimates returning close to zero approximately three weeks after each shock.

To use these results to estimate the slope of the convenient asset demand curve, I must also estimate how the quantity of T-bills changes over my impulse response horizon. I show that, while Wrightson surprises do not predict a permanent change in T-bill supply, they do predict higher T-bill supplies for several weeks. Supplies rise steadily in the three weeks following a surprise, before beginning their decline at week four. Supplies only return to their pre-surprise level eight weeks after a surprise.

I show that these two estimated impulse responses are consistent with the simple interpretation that *changes* in T-bill supplies have a larger effect on convenience yields than the *stock* of T-bills.[7] I do this by estimating separate stock and flow

days predicts movements in other financial variables, with an LP-IV setup that is similar to my own. In that paper, the author interprets these as Treasury supply shocks, but is transparent in discussing how their results depend on certain assumptions about the underling price elasticity of Treasury demand, in the spirit of my discussion above. In this paper, measuring that elasticity is my expressed goal, necessitating a different approach.

[7] This concept should be familiar to market participants and policymakers, who already frequently discuss Treasury borrowing using the identical concept of "net issuance"

effects of supply on convenience yields, via a multiple equation GMM approach. This procedure fits the same empirical moments as the LP-IV approach described above, but using fewer (two) estimated parameters. The identifying variation that separates flow and stock effects comes from the dynamics in the T-bill supply response over the impulse horizon. For instance, at horizons of four weeks or greater after a Wrightson surprise, the stock of T-bills is elevated relative to its pre-shock value, while the flow (change) in T-bill supply is sharply negative.

I also propose an alternate specification that trades a somewhat more restrictive, although similar, exclusion restriction for substantially more statistical power. In my baseline estimation, the flow effect is highly statistically significant, but the stock effect is not statistically significantly different from zero. The alternate specification leverages the high-frequency nature of the Wrightson projections, by including Wrightson's own *updates* in its projections of future T-bill supply, in the week of each surprise, as additional instruments. These results imply somewhat larger convenience yield effects, and tighter confidence intervals. Under this specification, both the stock and flow effects are statistically significant. Yet these results exhibit the same qualitative pattern as the baseline, that flow effects are large, and stock effects are small.

I show that estimated impulse responses for T-bill convenience yields and supplies of T-bill substitute assets are consistent with the stylized framework that led me to restrict the sample to those periods when the Fed's ONRRP facility is inactive. That is, I show how the response of convenience yields to T-bill supply shocks is muted in the subsample where the ONRRP facility is active. In those periods, convenience yields fall on impact, but return to zero more quickly. Instead, outstanding volumes of repurchase agreements appear to be the margin of adjustment: in ONRRP active weeks, repurchase agreement volumes move in the *opposite* direction of T-bill supplies, essentially one-for-one.

My results also indicate that, in ONRRP-inactive periods, outstanding volumes of the other likeliest substitute assets for T-bill convenience do not fall enough to seriously complicate my empirical estimates from those periods. Outstanding discount notes issued by the Federal Home Loan Bank system decrease, consistent with the FHLB issuing opportunistically. However, they decline only \$1.5 billion in response to a Wrightson surprise that moves T-bill supplies by approximately \$25 billion. Outstanding volumes of privately-issued, general collateral repurchase agreements show little reaction to T-bill supply shocks when the ONRRP is inactive.

This paper's separate estimates of flow and stock effects of T-bill supply are relevant for two, possibly-overlapping groups. For policymakers tasked with stabilizing money market rates, a powerful weeklong effect on yields is relevant to their policy objectives. To macroeconomists studying lower-frequency questions like the sustainability of the US fiscal position, the small permanent stock effect is likely most relevant.

My estimated flow effects are larger than convenience yield effects estimated by recent studies, while the estimated stock effect is smaller. In a recent study with a similar sample period, D'Avernas and Vandeweyer (2022) estimate that a \$100 billion increase in T-bill supplies depresses convenience yields by 4 basis points. My results share one important quality with theirs, that convenience yield responses to T-bill supply changes appear smaller in post-crisis data than in pre-crisis data. In the original, pre-crisis estimates of Greenwood et al. (2015b), a \$100 billion increase in T-bill supply depresses convenience yields by 8.27bp.[8]

To put my results in perspective, I demonstrate how they alter one of the positive conclusions from Mian et al. (2022), a leading study in the $R < G$ fiscal sustainability literature. In that paper, the sensitivity of government debt convenience yields to increases in debt issuance helps dictate what range of fiscal deficits appear sustainable in the United States, in the sense that they will lead to stable $\frac{Debt}{GDP}$ ratios in the long-run. In a calibration exercise corresponding to the US fiscal position as of 2019, the original estimates of Greenwood et al. (2015b) suggest a maximum sustainable fiscal deficit of 2.0% of GDP. Recent estimates from D'Avernas and Vandeweyer (2022) imply a maximum sustainable deficit of 2.4% of GDP. My point estimates, with other calibrations from Mian et al. (2022) unchanged, suggests a maximum deficit of 4% of GDP. The *largest* convenience yield stock impact that my estimates fail to reject at the 90% level implies a maximum deficit of 3% of GDP. My estimates suggest that the slope of convenience demand alone appears insufficient to meaningfully constrain the positive implications of Blanchard (2019), that large levels of US government debt and large deficits appear sustainable when nominal interest rates are low.

The rest of this paper proceeds in eight sections. In Section 2, I discuss the related literature. In Section 3, I clarify my structural parameters of interest with a simple model of convenient asset demand that is very similar to setups from Krishnamurthy and Vissing-Jorgensen (2012) and others. In Section 4, I provide important institutional details about T-bill issuance, such as the Treasury's commitment to avoid short-term opportunistic issuance. In Section 5, I use a stylized framework for understanding convenient asset supplies *other* than T-bills to explain how a post-crisis monetary policy tool effectively limits the post-crisis data sample for me methodology. In Section 6, I introduce Wrightson's T-bill issuance projections and their associated surprises (i.e. projection errors). I discuss the likeliest drivers of these surprises, and the ways in which these surprises improve upon the literature's standard approach of using seasonality instruments. In Section 7, I present my core empirical results regarding convenience yields and T-bill quantities. In Section 8, I present several estimates of interest regarding substitute asset supply, which are consistent with the story underpinning the core empirical results. Before conclud-

[8] The estimates of D'Avernas and Vandeweyer (2022) are most similar to mine in sample and methodology, and thus are the most-natural point of comparison to demonstrate that my estimated stock effects are *small* (and flow effects are *big*). However, the specification and research question of D'Avernas and Vandeweyer (2022) are sufficiently different from mine that one would not necessarily expect our estimates to be identical, as I discuss in Section 2.

ing, I demonstrate in Section 9 how my estimates affect the positive conclusions of one strand of the fiscal sustainability literature, as in Mian et al. (2022).

2 Related Literature

This paper contributes to several literatures at the intersection of macroeconomics and finance. First, is the literature studying the convenience yields on safe, liquid debt securities. Gorton (2017) places the importance of safe assets in the historical context, and summarizes certain theories of their special value of investors. Diamond (2020) shows how a financial sector that issues safe assets to households, financing a risky portfolio of nonfinancial sector loans, is the equilibrium outcome in an economy where households value safety and financial frictions in firm borrowing.

This paper most clearly belongs to the subset of this literature studying these convenience yields' empirical properties. Longstaff (2004) showed that the rates on Treasury securities are *lower* than any traditional asset pricing framework would suggest, given how they compare with equally risk-free bonds issued by the Resolution Funding Corporation following the S&L Crisis. Krishnamurthy and Vissing-Jorgensen (2012) brought the concept of convenience yields to the academic forefront, and introduced the concept of measuring key yield spreads to study the apparent marginal value of long and short-term safety and liquidity. That paper used its low-frequency empirical analysis as a way to test its central notion that convenience yields reflect a special quality of Treasuries, with marginal values that fall in the outstanding quantity. Krishnamurthy and Vissing-Jorgensen (2015) extends that analysis by studying aggregate volumes of safe, private sector bank liabilities, and shows how these quantities tend to fall when Treasury supply rises. Of course, it is worth noting that the large literature on convenience yields, and special investor demand for safety or liquidity attributes, is identical in many ways to the preferred habitat literature of Vayanos and Vila (2021). Indeed, a "preferred habitat" for short-term, convenient assets is the precise focus of this literature.

The literature that most resembles this paper's specific questions and empirical approach is that which studies variation in convenience yields and convenient asset supplies at high frequencies. Greenwood et al. (2015b), discussed at length above, showed how convenience yields in short-term T-bills vary with the quantity outstanding of those bills. Sunderam (2015) showed that private sector issuance of asset-backed commercial paper – a possible private sector substitute for T-bills – rises at high frequencies as the volume of T-bills rises. They show that their findings are consistent with a model featuring substitutability of private and public sector convenient assets. Infante (2020) studies how convenience demand interacts with the issuance of private *repurchase agreements* – themselves likely seen as convenient by investors – to finance holdings of long-term Treasuries. That study uses T-bill supply as a plausibly-exogenous shifter of demand for privately issued convenient assets, and features a high-frequency seasonality instrument in the spirit of Greenwood et al. (2015b). Klingler and Sundaresan (2023) shows how a proxy for T-bill demand from US primary dealers predicts movements in T-bill convenience yields since the financial crisis, suggesting that the demand of those agents (possibly driven by regulatory considerations) has become an important driving factor.

Recently, D'Avernas and Vandeweyer (2022) convincingly argued that the relationship between T-bill supply, private sector liquid asset issuance, and money market rates depends critically on the segmented nature of these markets, and on the availability of the Federal Reserve's ONRRP facility. That paper's focus was on testing the predictions of a structural model microfounding the interplay between private sector safe asset issuance, money market segmentation, and liquidity demand from a subset of money market investors. Their empirical specifications studying the effect of T-bill supply on convenience yields uses a seasonality instrument estimated in four-week differences, much like Greenwood et al. (2015b). That paper is transparent about their model *not* reflecting T-bill demand from government money market mutual funds – a large holder of T-bills in aggregate. As such, that paper does not directly study the question of interest in this paper, which is to estimate the *aggregate* elasticity of short-term convenient asset demand. At several points in this paper, I will reference the estimates of D'Avernas and Vandeweyer (2022), to help understand whether certain of my empirical estimates are large or small. This comes with the necessary caveat that that paper's empirical estimates are for a closely-related, but not identical, empirical question.

Other studies have discussed other implications of the ONRRP facility for convenient asset supply and demand. Ahnert and Macchiavelli (2021) show another way that the Fed's ONRRP facility has changed the nature of money markets, but providing money market mutual funds another source for liquid assets, to hold as insurance against investor outflows. Carlson et al. (2014) also addresses the potential for a close substitutability between ONRRP volume and T-bills, for market participants.

While not identical, a related literature makes measuring the substitutability of convenience from different asset classes its main focus. The first paper to make measuring convenience substitutability a primary focus was Nagel (2016), which stressed the need to consider the stance of monetary policy when studying the impacts of Treasury supply on convenience yields in low-frequency studies. Krishnamurthy and Li (2023) use low-frequency variation in rates and outstanding quantities of convenient assets to estimate elasticities of substitution between asset classes. Kacperczyk et al. (2021) show that short-term CDs in the Euro area appear to share some convenience substitutability with T-bills – although in times of market stress that substitutability appears to disappear. The subset of my results that are most relevant to this literature are those that measure movements in rates and volumes of assets *other* than T-bills after a T-bill supply shock. A fruitful direction for future research is to use this paper's notion of a T-bill supply shock to directly estimate that literature's parameters of interest, which are typically elasiticities of substitution between different safe asset classes.

This paper also belongs to a wider and more general literature that uses high frequency or event study methods to understand supply shocks in asset markets. Most relevant are those studies that study supply shocks in safe asset markets. Krishnamurthy and Vissing-Jorgensen (2011) study the impact of Quantiative Easing on bond yields in a classic event study. Gorodnichenko and Ray (2018) attempt to understand quantitative easing using a high frequency approach, focusing on unexpected *demand* revealed at Treasury auctions. Lou et al. show that supply changes in longer-term Treasury coupon security markets need not be *surprises* to have an impact on prices.

Given that my empirical results suggest that T-bill supply shocks have a *flow* effect that appears much larger than their stock (i.e. permanent) effect, my results provide evidence for theories that allow for overreaction in prices after an asset supply shock. Duffie (2010) shows how this may be caused by a subset of sluggish investors in markets, with potentially-elastic demand but only infrequent rebalancing practices. Particularly relevant for my setting, with shocks that occur amidst the highly-segmented US money market, Greenwood et al. (2018) document how price dynamics after a supply shock in one, partially-segmented market take time to affect other markets that are linked only by slow-moving, generalist arbitrageurs. In their model, prices in the market with a supply shock initially overreact to changes in supply, and prices of substitutes may underreact. D'Amico and King (2013), in another study on large-scale asset purchases by the US Federal Reserve, highlight seemingly-different stock and flow effects of Fed purchases, in much the same was as I do for T-bill supply shocks.

While the work described thus far shares a setting, method, or research question with this paper, there is a much wider literature in macroeconomics for which my identified parameter estimates will be relevant. The $R < G$ fiscal sustainability literature is immediately relevant, given the importance of the slope of convenient sovereign debt demand for that literature's quantitative conclusions. Relevant studies include Mian et al. (2022), Reis (2021), Blanchard (2019), Mehrotra and Sergeyev (2021), and Angeletos et al. (2023). Convenient asset demand curves likewise feature in a number of business cycle models, such as Kekre and Lenel (2021), Drechsler et al. (2018), and Bayer et al. (2023).

3 Model

In models with special investor demand for convenient assets, a yield spread between two appropriately chosen assets will measure the value to investors of the marginal unit of convenient assets. In a common, reduced form approach that is agnostic about the exact use source of this extrapecuniary value, I define the structural parameters that this paper estimates.

Most of the components of the model are standard, and replicate similar setups in Krishnamurthy and Vissing-Jorgensen (2012) and Greenwood et al. (2015b). Specifically, the representative investor has expected utility function

$$\mathbb{E}_0\left(\sum_{t=0}^{\infty}\beta^t u(C_t + v(\frac{B_t}{GDP_t}))\right)$$

where C_t is real consumption and B_t is the nominal volume of convenient assets. Like in Krishnamurthy and Vissing-Jorgensen (2012), the normalization $\frac{B_t}{GDP_t}$ internalizes the notion that greater income and spending should come with greater desire for the sort of liquidity benefits that convenient assets provide. The object $v(\cdot)$ is the convenience function, which captures total extrapecuniary benefits. The investor is subject to a standard flow budget constraint,

$$B_{t-1}(1+i_{t-1}^b) + A_{t-1}(1+i_{t-1}) + I_t = P_t C_t + B_t + A_t + T_t$$

This budget constraint introduces quantity notation for A_t, the investor's nominal investment in risk-free (but inconvenient) assets; I_t the investor's non-investment income; and T_t the investor's transfer income. It introduces interest rate notation for i_t^b the nominal net interest rate on bills; and i_t the nominal net interest rate on risk-free illiquid assets.

The standard first order conditions in this model say that the marginal convenience value should equal the current convenience yield. Call $\frac{B_t^*}{GDP_t}$ the quantity of convenient asset holdings at which this is true, so that

$$v_t'(\frac{B_t^*}{GDP_t}) = \frac{i_t - i_t^B}{1+i_t} \geq 0 \tag{1}$$

In other words, at this quantity B_t^*, the marginal interest earnings that an investor is willing to *forgo* by holding the marginal convenient asset should be exactly offset by the extrapecuniary value of marginal convenience.

As with other papers in the literature, I will assume a tractable parameterization for the marginal convenience function v'. I say that the marginal benefit of an additional unit of convenience declines linearly in the quantity of convenient assets held.

$$v'(\frac{B_t^*}{GDP_t}) = \alpha + \beta\frac{B_t}{GDP_t}^* + \xi_t = \frac{i_t - i_t^B}{1+i_t} \tag{2}$$

If the investor's actual holdings of convenient assets satisfy these first order conditions in each moment, then there is no need to define separate notions of short-run and long-run demand curves. A 1-unit, permanent increase in the outstanding quantity of convenient assets should lower convenience yields by β, instantly and permanently.

In the high frequency setting of this paper, there is reason to believe that the very short-run price impacts of a change in supply may differ from its long-run effects. The theoretical models of Duffie (2010) and Greenwood et al. (2018) have just such a feature. D'Amico and King (2013) document separate flow and stock effects of the Federal Reserves Large-Scale Asset Purchases program – which also featured Treasury securities. Lou et al. (2013) show that this phenomenon is not restricted to *surprise* supply shocks. Well-anticipated auctions sizes of longer-term Treasury coupon securities show a similar rebound effect. This paper's own empirical analyses to follow suggest that allowing for such differences is necessary to account for impulse responses to T-bill supply shocks.

I allow for this possibility in a simple way via an *inertia* equation for the investor's actual convenient asset holdings. Borrowing a setup from Gabaix and Koijen (2020), I write

$$\frac{B_t}{GDP_t} - \frac{B_{t-1}}{GDP_{t-1}} = \mu \left(\frac{B_t^*}{GDP_t} - \frac{B_{t-1}}{GDP_{t-1}} \right)$$

where $0 < \mu \leq 1$. This parameterization implies that actual convenient asset holdings respond only sluggishly to changes in the long-run optimal level of convenience holdings B_t^*. This particularly tractable setup suggests that this sluggishness lasts exactly one period, so that convenience yields settle to their new long-run level one period after a permanent supply shock. To see this, note that

$$\begin{aligned}
\Delta \frac{i_t - i_t^B}{1+i_t} &= \beta \Delta \frac{B_t^*}{GDP_t} + \Delta \xi_t \\
&= \beta \left(\frac{1}{\mu} \Delta \frac{B_t}{GDP_t} - \frac{B_{t-1}^*}{GDP_{t-1}} + \frac{B_{t-1}}{GDP_{t-1}} \right) + \Delta \xi_t \\
&= \frac{\beta}{\mu} \Delta \frac{B_t}{GDP_t} + \beta \frac{B_{t-1}}{GDP_{t-1}} + \alpha + \xi_{t-1} - \frac{i_{t-1} - i_{t-1}^B}{1+i_{t-1}} + \Delta \xi_t \\
\frac{i_t - i_t^B}{1+i_t} &= \alpha + \frac{\beta}{\mu} \Delta \frac{B_t}{GDP_t} + \beta \frac{B_{t-1}}{GDP_{t-1}} + \xi_t \\
&= \alpha + \beta (\frac{1}{\mu} - 1) \Delta \frac{B_t}{GDP_t} + \beta \frac{B_t}{GDP_t} + \xi_t \qquad (3)
\end{aligned}$$

I call equation (3) the *short-run convenient asset demand* curve, and it will serve as the primary estimating equation in the analyses to follow. I call equation (2) the *long-run convenient asset demand curve*. Equation (3) nests the possibility that $\mu = 1$, in which case long and short-run demand curves are identical. This paper aims to estimate both β and $\beta(\frac{1}{\mu} - 1)$.[9]

For most of this paper, my focus is on convincingly estimating the long-run slope of the convenient asset demand curve β, which most obviously relates to

[9] One could imagine characterizing the investor's sluggishness with more parameters. For instance, one might instead write

my estimates' applications in the macroeconomics literature. Those studies are primarily concerned with the long-run impacts of a one-time, permanent increase in the outstanding quantity of convenient assets (typically government debt). With this framework, I have clarified how the quantitative answer to that thought experiment might differ from the short-term responses that I estimate with high frequency data.

The difficulty in estimating the parameters of equation (3) is a familiar difficulty with estimating the slope of any demand curve: the objects B_t and ΔB_t may be correlated with the structural residual ξ_t. This represents other factors affecting the marginal value of extrapecuniary convenience. This object likely varies at high frequencies, for instance during much-discussed flight to safety episodes. For this reason, the VIX volatility index is sometimes considered as an observable empirical proxy for ξ. But ξ_t also likely varies at lower frequencies. Post-GFC changes to financial intermediary regulations could have made convenience either more or less valuable, depending on the intermediary.

4 Institutional Setting

Treasury bills are the most classic example of an asset that offers convenience attributes. The outstanding supply of T-bills is driven by the cash needs of the federal government. T-bill supplies exhibit substantially more high frequency variation than those of longer-term Treasury bonds, both because they are issued more frequently and because the Treasury prioritizes predictability in their supply less. To construct convenience yields, we compare T-bill rates to the fixed leg of an Overnight Indexed Swap (OIS) contract of similar maturity, as has become standard.

T-bills are a natural example of an asset that is convenient for investors to hold. As Feldhütter and Lando (2008) describe, Treasury securities have a number of qualities that might contribute to this convenience. Their accepted status as a nominally riskless instrument allows them to be used as high-quality collateral for short-term borrowing arrangements. A liquid secondary market means that T-bills can be sold with little price impact. T-bills also contribute favorably to the various regulatory requirements imposed on certain financial institutions.

$$B_t - B_{t-1} = \mu \left(\frac{B_t^*}{GDP_t} - B_{t-1}^* \right) + \phi \left(B_{t-1}^* - B_{t-1} \right)$$

with $0 \leq \phi \leq 1$. In that world, convenience yield responses to permanent supply shocks may take more than one period to settle to their long-run level. In Appendix B, I show that an alternate estimation procedure that allows for inertia of this form produces qualitatively similar estimates for the long-run convenience yield impact, but with larger standard errors. With a simulation-based bootstrap exercise, I also show that assuming my baseline, single parameter inertia equation when the true process is a two parameter version will tend to produce estimates of β that are biased *upward* in absolute value, but have substantially lower variance. As the central conclusion of this paper is that my estimated β is *small* in absolute value, such a bias, if present, would not change any of this paper's qualitative conclusions. In other words, estimation strategies based on Equation (3) perform favorably in the bias-variance tradeoff with that more-involved alternative.

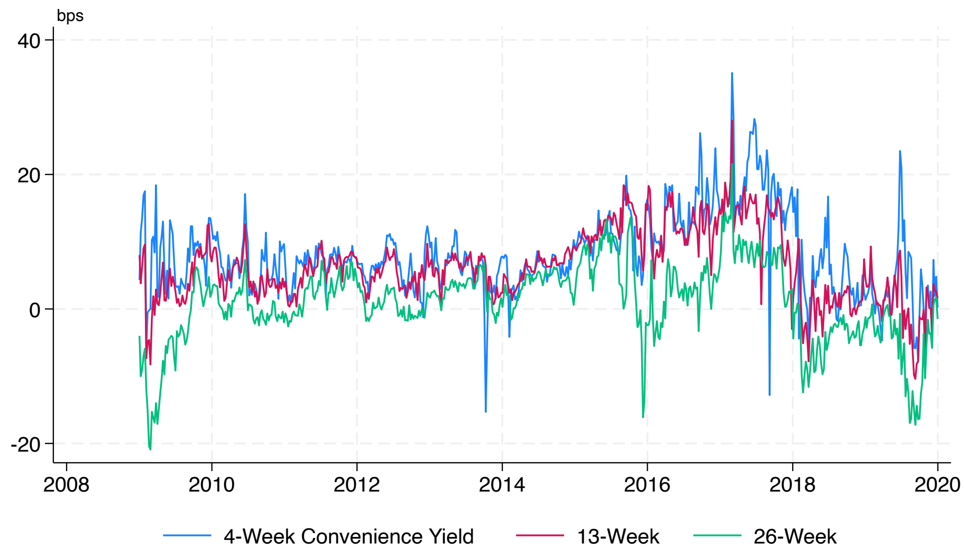
Likewise, the fixed leg of an OIS contract is a sensible proxy for the level of short rates, without any embedded risk or convenience premia. An overnight indexed swap is a fixed-length contract wherein one side agrees to pay a fixed interest payment at contract end, and the other pays the geometric average of the federal funds rate over the same period. No principal payments are exchange at maturity, nor are any additional payments made at contract start. My proxy for the short rate, without any embedded convenience attributes, is the fixed length on this contract. As Greenwood et al. (2015a) and Sunderam (2015) argue, the fact that OIS contracts are not a way to invest principal (and are thus not a store of value) makes it unlikely that this rate would include a convenience premium. It has been shown that these rates are also unlikely to reflect any counterparty risk, as in Feldhütter and Lando (2008).[10]

Consistent with the notion that T-bills enjoy a convenience yield, T-bill yields have been lower than OIS rates of the same maturity over my sample, mostly consistently. Figure 1 shows the difference between the quoted, fixed leg OIS rate and the yield on a like-maturity Treasury bill, at the 4, 13, and 26 week frequencies. With the occasional exception of the 26-week maturity point late in the sample, sustained negative realizations of the convenience yields have been rare, suggesting that T-bills offer an extrapecuniary convenience benefit to investors. [11]

[10] He et al. (2022) make the interesting point that, because OIS contracts are not a store of value, they also carry a smaller capital change for large financial institutions than Treasury securities. In that sense, the yield spread between OIS and Treasury rates may include a component of *inconvenience* value as well. Nevertheless, we might still expect marginal inconvenience to rise as the stock of T-bills rises, so that this mechanism still contributes to smaller convenience yields after increases in T-bill supply. Indeed, this is what He et al. (2022) assume. I do not view the difference between these two interpretations – declining marginal convenience versus increase marginal inconvenience – as critical to this paper's results.

[11] For the 4-Week convenience yield, which is most important to this paper's results, some short-lived negative realizations are clearly tied to debt ceiling impasses. Convenience yields in those unusual periods are the subject of Cashin (2023).

Figure 1: T-bill Convenience Yields



Note: T-bill convenience yields, at weekly frequency, from 2009-2019. Weeks are delineated by the 4-Week auction date, so that each realization is on such an auction date. Single-week spikes downward in the 4-Week maturity correspond to debt ceiling impasses. Convenience yields defined as $\text{OIS}_{m,t} - \text{T-bill}_{m,t}$ for each maturity m. Source: Federal Reserve Board of Governors H15 release, US Treasury via treasurydirect, Bloomberg, and Author's Calculations.

Week-to-week changes in the outstanding supply of T-bills are driven by fluctuations in the underlying financing needs of the US federal government. Fiscal outflows contribute positively to this cash need. These are government expenditures, including government consumption expenditures like payroll and military procurement, as well as transfer payments like Medicare and Social Security. Fiscal receipts contribute negatively to this cash need. These are almost entirely tax receipts (less tax refunds), including income taxes paid by individuals and corporate taxes paid by firms. The approximate timing of many of these flows, both outflows and receipts, is often predictable to an informed observer.

These financing needs can be met by one of two sources: net borrowing, or decreases in the balance of the Treasury's cash account. Since the 2008 Financial Crisis, functionally all of the Treasury's cash has been held in a reserve account at the Federal Reserve.[12] This reserve account operates in much the same way as the reserve account of a commercial bank. To finance net outflows arising from a week's expenditures exceeding a week's receipts, the Treasury can either permit the balance in this cash account to shrink, or increase debt issuance to limit the impact

[12] See Santoro (2012) for an informative summary of changes in Treasury cash management policy around this time.

on the cash balance.

The Treasury has a well-established goal to keep their debt issuance quantities "regular and predictable", but enforcing perfect predictability is infeasible[13]. In the face of sometimes-unexpected inflows and outflows, perfectly avoiding surprises to market participants by keeping debt issuance plans unchanged would carry an unacceptably-volatile balance in the cash account.

In practice, the component of debt issuance that the Treasury permits to sometimes fluctuate unpredictably is the supply of short-term T-bills. In principle, the Treasury could also allow its issuance of longer-term *coupon* securities to fluctuate in the face of funding need surprises. However, the Treasury appears reluctant to do so. In Appendix C, I show that *surprises* in coupon issuance, from the perspective of the well-informed market publication underpinning my surprise measure, are substantially less common than surprises in T-bill issuance.

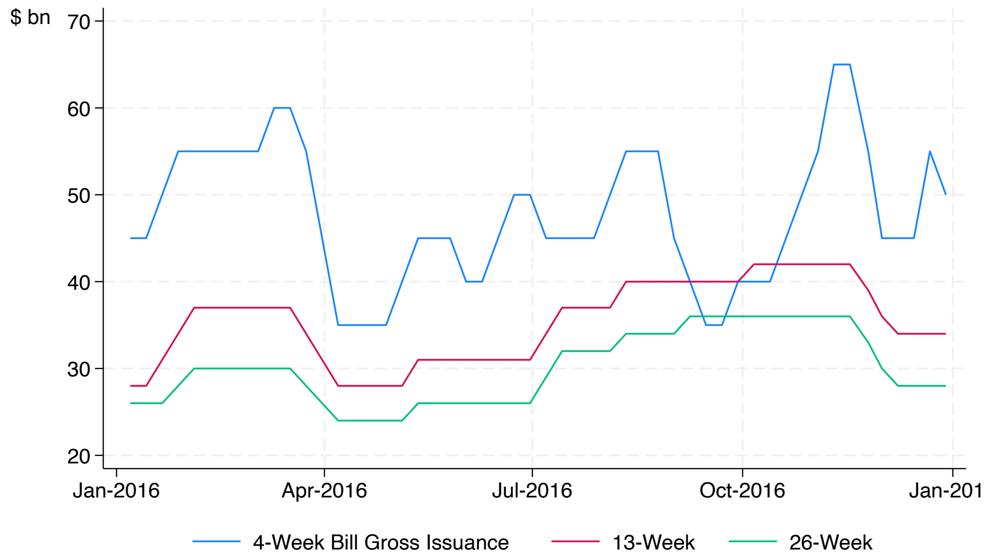
There are also major differences in issuance variability *within* the T-bill asset class. Over my post-crisis sample, T-bills are regularly issued in maturities of 4-Weeks, 13-Weeks, 26-Weeks and 52-weeks.[14] Figure 2 shows gross weekly issuance sizes, in billions of dollars of principal, for each of these maturities in 2016. Issuance sizes for 4-Week bills are substantially more variable than those for either of the longer maturities.[15]

[13] Garbade (2007) is an excellent historical primer

[14] In 2018, the Treasury also began issuing 8-Week bills.

[15] This pattern is born out over the rest of the sample: the standard deviation of week-to-week changes in issuance for the 4-Week bill is 0.03% of then-current nominal GDP. Standard deviations for the 13-Week and 26-Week bill issuance changes are both approximately 0.013%of nominal GDP.

Figure 2: Issuance Sizes of 4-Week, 13-Week, and 26-Week Bills in 2016



Note: T-bill weekly issuance sizes for regularly-issued bill maturities, in an representative example year, 2016. Source: US Treasury via treasurydirect, and Author's Calculations.

Treasury debt managers do not vary their issuance strategy to take advantage of short-term movements in demand for their debt. Figure 3 shows a presentation slide, taken directly from a debt management slide deck displayed prominently on the US Treasury's website. The phrasing on this slide is unambiguous: Treasury debt managers write "Treasury doesnt react to current rate levels or short-term fluctuations in demand". In Section 6.2, I discuss the role that this policy plays in my identification strategy.

Figure 3: A Summary of Treasury's Debt Issuance Philosophy

Note: A slide from a US Treasury presentation titled "An Overview of Treasury's Office of Debt Management". As of October 2023, this presentation is publicly available at Here. This presentation is displayed somewhat prominently alongside the Treasury's Quarterly Refinancing documents, here. Source: US Treasury via https://home.treasury.gov/system/files/276/Debt-Management-Overview.pdf.

In discussions, economists often find this practice difficult to reconcile with the "Objective" on this slide, to "Fund the government at the least cost to the taxpayer over time." It seems conceivable that timing debt issuance to coincide with higher demand for Treasury debt might lead to lower financing costs. The Treasury does not appear to share that interpretation. Rather, debt managers appear believe that keeping debt issuance uncertainty low for investors keeps the Treasury's borrowing costs lower, in the long-run. In 1982, the Treasury deputy assistant secretary summarized their logic, when saying "regularity of debt management removes a major source of market uncertainty, and assures that Treasury debt can be sold at the lowest possible interest rate consistent with market conditions at the time of sale."[16] Other portions of the slide deck featured in Figure 3 suggest that the justification for

[16] Glasserman et al. (2017) features an informative and insightful discussion of the history, costs, and benefits of this strategy.

this strategy has not fundamentally changed in the intervening years.[17] While this justification does seem plausible, in reality it is not important for my identification strategy that this practice be *optimal* for the Treasury. It is only important that the Treasury *perceives* it as optimal, which they appear to do.

5 Estimation Challenges with T-bill Substitutes

This paper will use a notion of T-bill supply shocks to estimate the slope of convenient asset demand. Doing this is complicated by the possibility that supplies of T-bill convenience *substitutes* may vary after the shock. As D'Avernas and Vandeweyer (2022) argue with a slightly different model, this issue is likely most-severe when the Fed's overnight reverse repurchase agreement (ONRRP) facility is active. I demonstrate this intuition using a simple, stylized, linear supply and demand framework. Given this issue, I will limit my estimation sample for convenience yield effects to those periods when the ONRRP facility is *not* active.

5.1 Pre-ONRRP Estimation Problem

First, I discuss how an endogenous supply of convenience substitute assets would complicate my estimation, in the basic setting without the Federal Reserve's ONRRP facility.

While the discussion of Section 3 focused on T-bills as the only source of short-term convenience, there are almost surely other assets that satisfy a similar desire from investors for convenience. Two likely candidates are Federal Agency securities and certain overnight repurchase agreements that are used by money market participants to invest principle.[18] While not as liquid as T-bills, short-term agency securities are still backed by the full faith and credit of the US federal government. As such, to the extent that T-bill convenience is directly tied to the virtually-zero default risk of T-bills, then agency securities likely share that quality. Similarly, safe overnight repurchase agreements are overnight lending agreements that are *collateralized* with safe assets like US Treasury or agency securitites. Given that repurchase agreements are usually for overnight lending, default risk is low and liquidity is high (in the sense that repurchase agreements are *daily* convertible to cash via redemption). Finally, if convenience is driven by the regulatory desirability of convenient assets, then T-bills, Agencies, and repurchase agreements collateralized by Treasuries or Agencies are likely similarly convenient.[19]

[17] One such slide is featured in the Appendix D.

[18] A repurchase agreement (repo) is a financial contract in which one party sells a security to the other, and pledges to repurchase the security at a later date. Most repos are for overnight maturities, so that repurchase occurs on the following day. One side in the transaction is fundamentally a cash investor. The other is fundamentally a cash borrower, offering the exchanged security as collateral.

[19] For instance, government-only money market mutual funds, which have a restricted set of allowable investments, can typically invest in any all three of these asset classes.

If investors view the convenience properties of these alternate investments as substitutable with the convenience of T-bills, then the demand curve in equation (3) is misspecified. Instead, we might write

$$\frac{i_t - i_t^B}{1+i_t} = \alpha + \beta(\frac{1}{\mu} - 1)\Delta\frac{Q_t}{GDP_t} + \beta\frac{Q_t}{GDP_t} + \xi_t$$
$$Q_t = B_t + RP_t + \text{Agency}_t$$

where RP_t are outstanding general collateral repurchase agreements (repo), and Agency_t are outstanding Agency securities.[20]

This corresponds to the case where convenience from these three sources are *perfect* substitutes for one another. Using Wrightson T-bill issuance surprises to *estimate* the degree of substitutability between these asset types is an interesting direction for future research, but is outside the scope of this paper.[21]

In this case, using changes in T-bill supply as proxies for changes in Q may not yield consistent estimates of β. Suppose that a researcher has isolated a component of T-bill supply B_t that is uncorrelated with the unobservable components of convenient asset demand, ξ_t (I discuss the manner in which I have done so shortly, in Section 6.2). For expositional purposes, suppose that $\mu = 1$, so that a 1-unit change in $\frac{Q_t}{GDP_t}$ will tend to depress convenience yields by β immediately, all else equal. In this world, we will have

$$\frac{d}{d\text{B}_t}\left(\frac{i_t^{\text{Ref}} - i_t^{\text{B}}}{1+i_t^{\text{Ref}}}\right) = \beta\frac{dQ_t}{dB_t} = \beta\left(1 + \frac{dRP_t}{d\text{B}_t} + \frac{d\text{Agency}_t}{d\text{B}_t}\right) \leq \beta \tag{4}$$

This convenience yield response will depend in part on $\frac{dRP_t}{d\text{Bills}_t}$ and $\frac{d\text{Agency}_t}{d\text{Bills}_t}$. In general, we would expect both of these objects to be weakly *negative*. When T-bill supplies rise, convenience yields on both T-bills and their convenience substitutes will tend to fall. Because non-Treasury issuers of convenience substitutes may well issue opportunistically, they could respond to this price change by decreasing issuance quantities. The quantitative importance of this mechanism will depend on the size of $\frac{dRP_t}{d\text{B}_t}$ and $\frac{d\text{Agency}_t}{d\text{B}_t}$.

[20]The market for all repo borrowing in the United States is extremely large. I wish to focus attention on the segment of this market that is frequented by investors looking for short-term investments of their cash principle. These are the investors that might view a repo as substitutable for a T-bill. This does not include, for instance, those market segments where the primary motivation for trading is securing a particular security as collateral. It also does not include securities lending transactions, even though the mechanics of those contracts are functionally identical to repos.

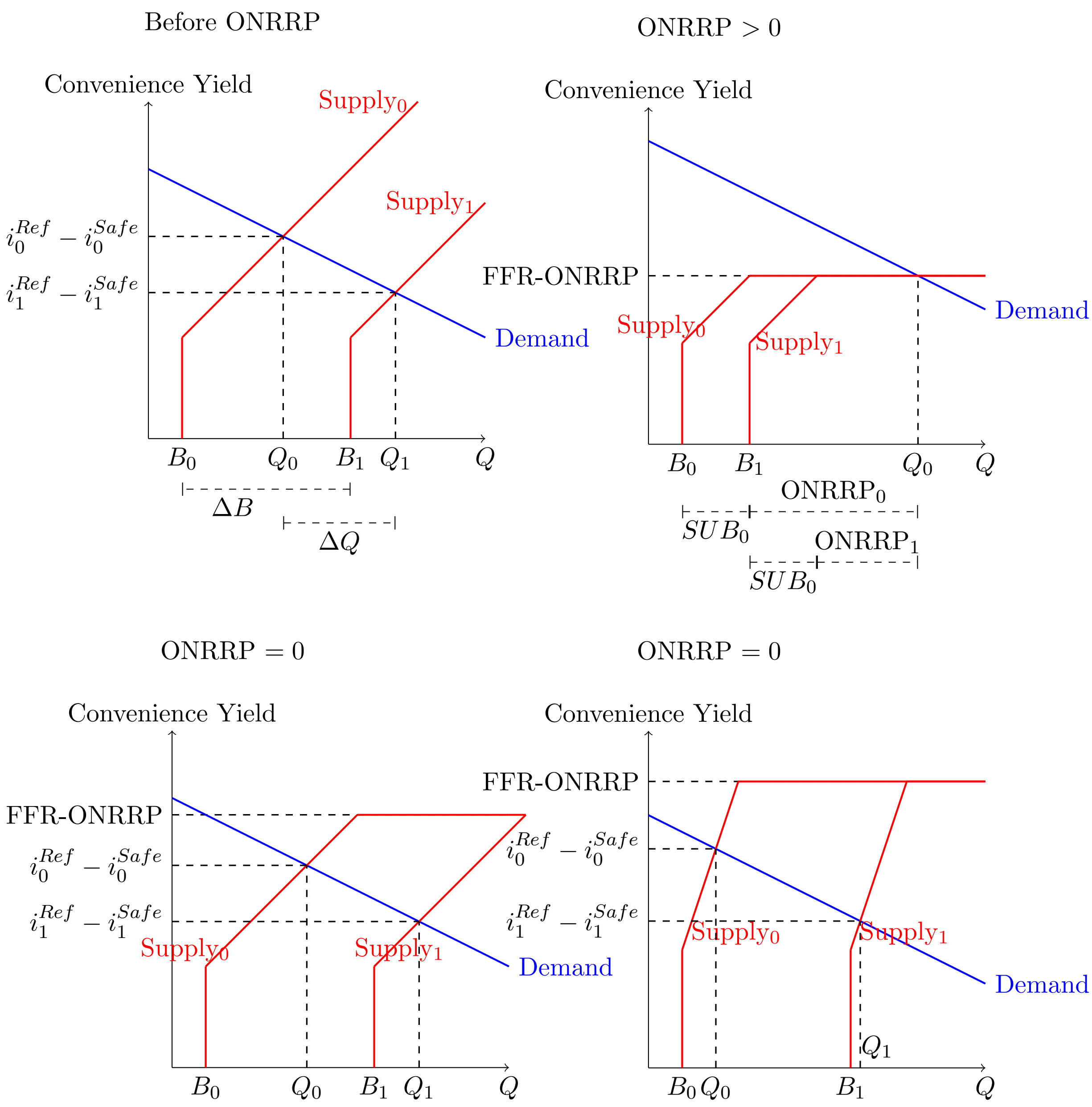
[21]For instance, we might parameterize a more general case of possibly-imperfect substitutability as

$$Q(B_t, RP_t, \text{Agency}_t) = (B_t^\rho + RP_t^\rho + \text{Agency}_t^\rho)^{\frac{1}{\rho}}$$

The discussion in this section assumes the case where $\rho = 1$. In principle, one can use this relationship as the basis for estimating ρ. That is the focus of Krishnamurthy and Li (2023).

The upper-left panel of Figure 4 visualizes a stylized, linear supply and demand framework is sufficient to discussing the problem. My econometric task is to use variation in B_t to identify the slope of the depicted demand curve, $\beta < 0$. In time 0, total safe asset supply equals $B_0 + SUB_0$ where $SUB_t = \text{Agency}_t + RP_t$ ("SUB" for "substitutes"). The supply curve is shown in red, the demand curve is in blue and equilibrium convenience yields and quantities are determined by the intersection. The other three panels of Figure 4 will be discussed in the following subsection.

Figure 4: Stylized Convenience Yield Responses, by ONRRP State



Note: Expected influence of the Fed's Overnight Reverse Repurchase Agreement (ONRRP) facility on the convenience yield response to T-bill supply shocks. Uses a simple, linear supply and demand framework described in the text. Source: Author's calculation.

As argued above, it is unlikely that the US Treasury's T-bill issuance decisions are opportunistic. In other words, it is unlikely that T-bill supply depends directly on convenience yields. In the diagram, this is reflected in a vertical region of the supply curve

Each supply curve has a region where total quantities rise in convenience yields. When issuers of substitute assets are issuing strictly positive quantities of those assets, then the total convenient asset supply curve may be upward-sloping. This is driven by the possibly-opportunistic (i.e. rate sensitive) issuance of repurchase agreement issuers and, possibly, US government agencies like Fannie Mae, Freddie Mac, and the Federal Home Loan Banks.[22]

The upper-left panel allows us to consider the effect of an increase in T-bill supplies B that are not accompanied by any shift in the demand curve. I depict this via a shift in the supply curve from Supply_0 to Supply_1.

In this setting, a T-bill supply shock can be used to identify the slope of the demand curve, β. However, the demand curve's slope is identified as

$$\beta = \frac{i_1^{Ref} - i_1^{Conv} - i_0^{Ref} - i_0^{Conv}}{Q_1 - Q_0}$$

.

In the depicted example, this is not equal to $\frac{i_1^{Ref} - i_1^{Conv} - i_0^{Ref} - i_0^{Conv}}{B_1 - B_0}$. That is – assuming that the change in T-bill supply equals the total change in convenient asset supply will give an incorrect estimate of β.

One could imagine resolving this issuing by measuring $\frac{dQ_t}{dB_t}$ directly, using high frequency data on RP_t and Agency_t. This is straightforward in principle, but difficult in practice. High frequency data on outstanding repurchase agreement volumes has only recently become publicly available. Similarly, it is challenging to directly measure the outstanding volume of US Agency discount notes at high frequencies.[23]

With this caveat on data availability in mind, I will demonstrate in Section 8 that publicly available data suggests $\frac{dQ_t}{dB_t} \approx 1$ for my T-bill supply shocks, in the sample period where the upper-left panel of Figure 4 is a sensible depiction of market supply. The next subsection outlines why the Fed's ONRRP facility makes that panel a poor approximation of reality for the remainder of the sample.

[22] Some readers may question whether a private actor issuing a repurchase agreement reflects a *net* creation of convenient assets, in aggregate. If the asset used to collateralize the repo is itself a short-term, convenient asset, then it may not, given that the cash borrower must relinquish that collateral to the lender for the duration of the contract. However, if the repo is collateralized with a default-free, but longer-term security like a Treasury coupon note, then the repo may create convenient assets, on net. This paper is about the special investor demand for short-term convenient assets, which Krishnamurthy and Vissing-Jorgensen (2012) convincingly argue are largely separate from the convenience attributes of longer-term safe securities. A repo collateralized by a long-term Treasury, in that sense, creates a greater supply of short-term convenient assets.

[23] This is because, unlike for T-bills, many US agency securities are issued both via a regular, well-document auction system, and via a daily issuance "window" that is often less transparently documented.

5.2 The Estimation Problem, with the Fed's ONRRP Facility

In a world where T-bills and repos have perfectly substitutable convenience, The Fed's ONRRP facility makes a portion of the market supply curve for convenient assets perfectly elastic. I demonstrate why this is problematic for my estimation, motivating an important sample restriction for my empirical analyses of the effect of T-bill supply shocks on convenience yields.

Whatever relationship exists between convenience yields and substitute safe asset issuance was undoubtedly altered by the Federal Reserve's introduction of the standing ONRRP facility. The ONRRP facility is a monetary policy implementation tool introduced in 2013 that allows cash investors in US money markets to "purchase" repurchase agreements from the Fed. The interest rate on these repo agreements is predetermined by the Federal Open Market Committee, and does not fluctuate in response to short-run market movements. The monetary policy goal of this facility is to enforce a Fed-determined *floor* on a wider range of money market rates.

Because the Federal Reserve predetermines the interest rate at which they are willing to issue repurchase agreements, the ONRRP limits the ability of repo convenience yields to move in response to shocks.[24] In a world where repo and T-bill convenience are perfect substitutes, this will also limit the responsiveness of T-bill convenience yields to shocks.[25]

The upper-right panel of Figure 4 shows how this process operates in our stylized setting. In this depiction, the Federal Reserve commits to providing a perfectly-elastic supply of repurchase agreements to money market participants, so that equilibrium convenience yields equal the level consistent with the Fed's choice of ONRRP rate and overall short-term rates. This practice creates a *flat* portion in the convenient asset supply curve, at the convenience yield consistent with that level. The upper-right panel also allows us to see the equilibrium division of convenient assets between T-bills B_0, Private Repurchase Agreements and Agency Securities Sub_0, and ONRRP volume $ONRRP_0$.

The movement from period 0 to period 1 in the upper-right panel shows the expected effect of a T-bill supply shock on convenience yields and safe asset supplies, again without any accompanying movement in the demand curve. In a stylized world

[24] For instance, one definition of the repurchase agreement convenience yield might be $\text{IOER}_t - \text{Repo Rate}_t$, where $IOER$ is the interest on excess reserves determined by the FOMC. Under this definition, by issuing repurchase agreements at an FOMC-determined rate, the Fed directly chooses *both* the convenient asset yield and the reference asset yield in this relationship.

[25] A less extreme story that is consistent with the results shown in this paper is that the marginal, "fast" T-bill investor that is able to quickly respond to T-bill supply shocks views T-bill and repo convenience as only imperfect substitutes. This is consistent with a results show in Appendix I, that Treasury-only money market funds provide most of the market elasticity immediately following a T-bill issuance surprise. Treasury-only funds cannot hold repurchase agreements – only Treasuries. In that world, we might expect T-bill supply shocks to have some convenience yield impact in the short-run.

of perfect substitutability, the increase in T-bill supplies from B_0 to B_1 has no effect on the convenience yield. However, the increase in T-bill supplies decreases the issuance of repurchase agreements at the ONRRP, from $ONRRP_0$ to $ONRRP_1$.

An important practical detail of the ONRRP is that its volume cannot be strictly negative. The Federal Reserve uses the facility to *issue* repurchase agreements to money market investors (i.e. borrow cash). The Federal Reserve does not respond to low convenient asset demand by purchasing repurchase agreement (i.e. lending cash).

A scenario where takeup at the ONRRP is zero is depicted in the bottom-left panel of Figure 4. In this setting T-bill supply shocks once again have convenience yield effects. The bottom-right panel is functionally the same as the upper-left panel, in which the ONRRP did not exist. An ONRRP facility with zero takeup is identical, from the perspective of identifying β, to no ONRRP facility at all.

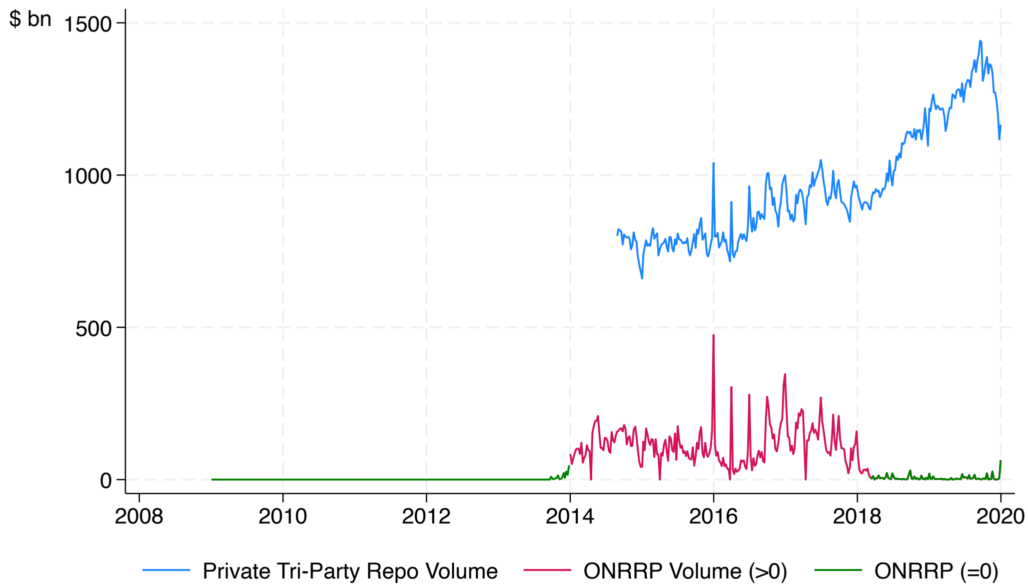
The bottom-right panel of Figure 4 makes the point that the bias induced by using $\frac{i_1^{Ref}-i_1^{Conv}-i_0^{Ref}-i_0^{Conv}}{B_1-B_0}$ to estimate β instead of $\frac{i_1^{Ref}-i_1^{Conv}-i_0^{Ref}-i_0^{Conv}}{Q_1-Q_0}$ depends crucially on the *slope* of the private substitute asset supply curve. A supply curve closer to vertical implies less bias, because $Q_1 - Q_0 \approx B_1 - B_0$ when the supply curve is more vertical (i.e. as the substitute asset supply response approaches zero). But this is unhelpful in a world where $ONRRP > 0$. When ONRRP takeup is strictly positive, that necessarily introduces a perfectly elastic portion to the convenient asset supply curve, regardless of the rate sensitivity of non-Fed issuers.

5.3 Empirical Takeaways

Ignoring the endogenous supply response of T-bill substitutes to T-bill supply shocks will tend to bias our estimate of β towards zero. This bias becomes less quantitatively important when substitute asset supplies are *less* responsive to changes in convenience yields. When the Fed's ONRRP facility is not active, this depends on the convenient asset issuance behavior of private repo issuers and Federal Agencies like the FHLBs. I will show evidence that those suppply responses do not appear large enough to meaningfully alter my estimates of β. Estimation when the ONRRP facility is active are likely more problematic, because quantity at the ONRRP is perfectly rate elastic by construction. I will avoid using data in those periods to draw any conclusions about β.

Figure 5 shows takeup volumes at the ONRRP facility over my sample. This is exactly equal to zero before the facility was first implemented. It is meaningfully greater than zero for a period from 2014 to 2018. It is close to zero from 2018-2020. The figure also shows the "ONRRP=0" period that I use as the ONRRP inactive period. This includes the 2018-2020 period, the ONRRP volumes are often strictly positive, but fairly close to zero.

Figure 5: Cash Investor Repurchase Agreement Volumes



Note: Shows volume in private tri-party repo and at the Fed's ONRRP repo facility. Private tri-party repo volume date became publicly available via the US Treasury OFR's Repo Markets Data Release starting in August 2014. The ONRRP facility was first implemented in September 2013. Takeup became consistently large beginning in 2014, before returning again to small values for 2018-2019. Weekly realizations plotted are *daily* realizations on the day of a given week's 4-Week T-bill auction, consistent with the convention in Figure 1. Sources: US Treasury Office of Financial Research via its Repo Market Data Release; Federal Reserve Bank of New York via its ONRRP volume release.

6 A New Measure of T-Bill Supply Shocks

Identification in this setting requires isolating a component of week-to-week convenient asset supply that is uncorrelated with week-to-week variation in convenient asset demand. I introduce a notion of T-bill issuance *surprises*, based on projections from Wrightson's Money Market Observer. I argue that these surprises plausibly satisfy my exclusion restriction, and have several advantages over identification via *seasonal* T-bill supply variation.

6.1 Identification

I define the exclusion restriction necessary for identifying the impulse response function of T-bill convenience yields to a T-bill supply shock.

In this paper, my central empirical analyses will be estimated via a local projection, instrumental variables (LP-IV) approach. That is, I will be estimating equations of the following general form via 2SLS

$$
\begin{aligned}
\text{2nd: } \frac{i_{t+h} - i^B_{t+h}}{1 + i_{t+h}} &= \alpha_h + \beta_h \frac{B_t}{GDP_t} + \gamma_h' X_t + e_{t+h} \\
\text{1st: } \frac{B_t}{GDP_t} &= \psi_1 + \zeta z_t + \phi_1' X_t + w_{t+h} \\
h \in \{0, 1, 2, \cdots, H\}
\end{aligned}
$$

where X_t are control variables and z_t is an instrument for T-bill supply B_t. This procedures describes estimating a separate second stage equation for each horizon h of interest. The coefficients of interest in this estimation are the sequence of $\{\beta_h\}_{h=0}^H$.

Our impulse response function of interest is the impulse response for an increase in T-bill supply at time $t = 0$. As such, our objective is for β_h to be a consistent estimator of that object, so that

$$
\beta_h \to \mathbb{E}\left(\frac{i_{t+h} - i^B_{t+h}}{1 + i_{t+h}} | B_t = \bar{B} + 1, X_t\right) - \mathbb{E}\left(\frac{i_{t+h} - i^B_{t+h}}{1 + i_{t+h}} | B_t = \bar{B}, X_t\right)
$$

That is, we want β_h to measure the effect of a 1-unit larger realization of B_t on projections of the convenience yield h periods hence.

Recalling the structure of equation (3), where ξ_t denotes unobservable factors shifting the convenient asset demand curve, consistency will following from the conditions

$$
\begin{aligned}
\mathbb{E}(B_t^\perp z_t^\perp \neq 0) \qquad (5) \\
\mathbb{E}(\xi_t^\perp z_t^\perp = 0) \qquad (6) \\
\mathbb{E}(\xi_{t+h}^\perp z_t^\perp = 0), \qquad (7) \\
h \in \{0, 1, \cdots, H\} \qquad (8)
\end{aligned}
$$

where $x_{t+j}^\perp = x_{t+j} - \text{Proj}(x_{t+j} | X_t)$.

6.2 Surprises As Instruments

In this paper, I will use T-bill issuance surprises from a highly-informed market newsletter as an instrument for T-bill supply. That is, letting $\mathbb{E}_{Priv,t-\delta}\left(\frac{B_t}{GDP_t}\right)$ be a measurement of private-sector expectations of time-t T-bill supply, formed at time $t - \delta$, I will say

$$
z_t = B_t - \mathbb{E}_{Priv,t-\delta}\left(\frac{B_t}{GDP_t}\right)
$$

Researchers in this literature most-commonly discuss an endogeneity worry driven by opportunistic issuance. If the Treasury tends to respond to fluctuation in demand by issuing more or fewer T-bills, then that will tend to induce a correlation between B_t and ξ_t.

My instrument addresses this concern by invoking the Treasury's policy from Figure 3 that it "doesn't react to current rate levels or short-term fluctuations in demand." I assume what seems like a natural consequence, which is that, when the Treasury surprises private actors with their T-bill issuance, they are not doing so *in response* to some fluctuation in demand for Treasury debt.

The dual facts that my analysis is at high frequencies and uses very-recent projections make this logic possible. While the Treasury does not react to "short-term" fluctuations in demand, but there is no policy prohibiting them from reacting to a lower-frequency, longer-term demand fluctuation.[26] As such, this argument for identification will tend to become less valid in lower-frequency analyses. At the yearly or quarterly frequency, the Treasury may or may not view an issuance reaction to demand conditions as "reacting to short-term fluctuations in demand". In this paper I only argue that over horizons of several weeks they certainly would.[27]

The standard approach in this literature is to use as an instrument a measure of *seasonally-expected*. This alleviates concerns about opportunistic issuance because this dimension of variation comes from some *other*, well-understood sources. Seasonal variation in T-bill supply is undeniably driven by the predictable timing of tax receipts and certain payments like Social Security, Medicare, and military payroll. Naturally, because this variation in T-bill supply is expected, that source of variation is incompatible with the impulse response logic and framework introduced above. Instead, this literature typically estimates the effect of T-bill supply changes in a single-equation approach, based on Equation (2).[28]

Focusing on T-bill issuance *surprises* as an alternative to resolve the opportunistic issuance problem is empirically attractive for two reasons. First, it permits the use of the impulse response estimation methods outlined above. This allows me to transparently show dynamics in the convenience yield response after a T-bill supply shock. As I will show below, these dynamics are empirically meaningful, and affect the qualitative nature of one's conclusions about whether the convenient asset demand curve is flat or steep.

Second, my instrument is more robust to the possibility that *demand* for short-

[26] Indeed, in a different presentation slide included in the Appendix D, the Treasury notes that they will "slowly adjust to shifts in expected cost." This seems to open the door to a policy of lower-frequency opportunistic issuance.

[27] To provide a concrete example: It is the impression of some market participants that the Treasury responded to money market fund reforms in 2016 by increasing their issuance of T-bill. This may or may not have been the case. However, even if true, that plausibly would *not* be interpreted as a "short-term" fluctuation in demand, and thus may not directly contradict Treasury policy.

[28] Most common is to estimate equation (2) in four-week differences, with some notion of seasonal T-bill supply as an instrument.

term convenient assets is seasonal. If convenient asset demand has a seasonal component, then the validity of a seasonal supply instrument relies on the seasonal components of demand and supply being uncorrelated. That sort of correlation might exist by happenstance. For instance, empirical work in finance has convincingly shown that financial institutions manage their balance sheets in different ways at the ends of months or quarters, because of the predictable seasonality in when post-crisis leverage constraints are most binding[29]. This could plausibly alter those institutions' demand for T-bills are month or quarter-end.

A correlation between seasonal T-bill supply and seasonal T-bill demand could also be driven by the same calendar events that drive the Treasury's seasonal cash needs. If individuals or corporations tend to move their expected tax payments into convenient assets (which are highly liquid) prior to a major tax deadline, then liquidate those assets upon tax payment, then that will tend to induce a positive correlation between between seasonal T-bill supply and demand. T-bill supply *rises* in the lead-up to major tax deadlines, then falls afterwards. In Appendix A.3, I show that the structural demand residuals implied by my estimates of β and μ in equation (3) imply a positive correlation between seasonal Treasury supply and demand.[30]

If T-bill issuance surprises are not driven by the Treasury responding to demand shocks, then what are they driven by? I argue below that they are driven by differences in private actors' and the Treasury's projections of near-future tax receipts and expenditures. The Treasury surprises market participants with larger issuance (i.e. more borrowing) when they expect greater near-future net *outflows* than private actors do.

In Appendix F, I address a remaining challenge to identification: That high frequency T-bill surprises, through their informativeness about future government cash flows, carry some additional macroeconomic information that is independently relevant to convenient asset demand. For instance, because government tax receipts are undeniably cyclical, a positive T-bill surprise today, which predicts lower government inflows in the near-future, could conceivably suggest that the economy is headed towards a recession.

I offer two results that argue this sort of mechanism should be small. First I show that, even at quarterly frequencies, surprises in government receipts and expenditures appear much more disconnected from the state of the macroeconomy than surprises in other, more-closely watched macroeconomic indicators like housing starts, unemployment, and industrial production. I do this using newly-digitized

[29] See Du et al. (2018), Anbil and Senyuz (2018), and Munyan (????)

[30] In Appendix A.2, I also demonstrate a curious quality of seasonality instruments in post-crisis data: They do not share the same relationship with OLS estimates that the original logic (and original estimates, given their pre-crisis sample) of Greenwood et al. (2015b) suggests. Estimates via seasonality instruments imply smaller convenience yield changes after T-bill supply movements than OLS estimates. This conflicts with the interpretation that seasonality instruments *remove* an underlying, positive correlation between demand the supply. This suggests that the seasonality of T-bill supply and demand could very well have *changed* in some important way since 2008.

data on projections (and thus surprises) of these variables from the FOMC's Tealbooks. These results do not suggest that government expenditures and receipts are acyclical. Rather, they suggest that the cyclical component of fiscal flows is mostly *expected*, at high frequencies.

Second, I show that the T-bill issuance surprises that are likely to be most informative about the business cycle have convenience yield impulse responses that are nearly identical to those that are less informative. Because tax receipts are more-closely tied to output and income than expenditures, T-bill issuance surprises near major tax deadlines are likely most-informative for macreconomic fundamentals. The fact that convenience yield responses to T-bill surprises in those weeks is extremely similar to responses to surprises at other times suggests that any modest informativeness of T-bill surprises for the macreconomic is unlikely to come with any sizable convenience yield response over the horizons that I study. As such, it is unlikely to threaten my exclusion restriction

6.3 Wrightson Supply Projections

Wrightson's projection errors of 4-Week T-bill issuance will serve as our proxy for T-bill issuance surprises. Wrightson projections for 4-Week T-bill issuance offer an unusually rich dataset of private projections of our independent variable of interest. They are released soon before each 4-Week T-bill auction, and are reevaluated frequently with the most up-to-date market information.

In this paper, I use T-bill issuance projections from Wrightson ICAP as a proxy for private market expectations of the Treasury's issuance decisions. Wrightson ICAP is an independent research firm, founded in 1978, with data available by subscription. Wrightson's research team delivers high frequency projections of a number of data releases relevant to money markets and to the macroeconomy, including overnight funding rates, FOMC interest rate decisions, and employment data releases, among many others. Wrightson's chief economist is frequently quoted in articles by other business news publications, typically discussing issues of Treasury finance and Fed policy.

Wrightson's T-bill issuance projections are very granular. Each set of projections delivers a prediction about the quantity of bills to be auctioned in every one of the T-bill maturities auctioned on a regular basis. Each set of projections delivers a projection for every such auction in the following eight to nine weeks.

Wrightson's T-bill projections are updated regularly and frequently, using the most up-to-date available information relevant to Treasury financing. Wrightson typically releases its weekly Money Market Observer publication in the late evening on Sunday or very early morning on Monday. Each Money Market Observer publication includes a table of T-bill projections, for the following eight to nine weeks of auctions.

Through the text of the Money Market Observer newsletter, as well as the shorter but-more focused daily Treasury Commentary newsletter, one obtains an unusually rich lens into the thought process of the forecaster. Through this commentary, it is clear that Wrightson's projections are based on a wide range of data sources, including daily Treasury cash flow releases from the Daily Treasury Statement; the latest debt ceiling negotiations or fiscal spending debates; expertise on often-obscure seasonalities in cash flows; and the Treasury's perceived intentions, partially revealed through their recent issuance patterns.

I define my measure of a T-bill issuance surprise to be Wrightson's same-week projection error for the quantity sold at the Treasury's auction for the 4-Week T-bill. I do this for several reasons. First, the 4-Week bill is the regularly-auctioned T-bill whose issuance quantity exhibits meaningful high-frequency variation. Thus, the 4-Week bill's size is the least predictable of the regular bills that are auctioned over the entirety of my sample, leaving a shock measure with ample variance. Second, the size of the 4-Week T-bill is announced by the Treasury very soon after Wrightson publishes their issuance projections for the week. For most of my sample, 4-week bill sizes are announced on Monday afternoon, approximately half a day after Wrightson publishes their projections. This increases the chance that my shock does indeed surprise markets, when it is realized. Third, focusing on supply surprises of a regularly-auctioned bill increases my certainty that surprises in my measure are not driven by any opportunistic issuance. Regularly-scheduled bill auctions are bound by the Treasury's goal of regular and predictable issuance, which is the justification for avoiding opportunistic issuance. While I have not seen any statements by the Treasury that explicitly lead me to believe that opportunistic issuance is a greater problem for the more irregularly-auctioned cash management bills, the fact that those bills are clearly less bound by the regular and predictable principle naturally decreases one's certainty.

6.4 Time Series Properties

Consistent with their interpretation as rational market expectations, Wrightson T-bill supply projections have substantial forecasting power, at all relevant horizons. Modest positive serial correlation in the surprises, as well as a negative correlation with the projection size, will inform our choice of controls in the analyses to follow.

Wrightson's 4-Week T-bill issuance projections exhibit substantial in-sample predictive power, meaningfully outperforming simple time series techniques for projecting future issuance. In Table 1 below, I regress current 4-Week T-bill issuance sizes on different combinations of predictors. In the first, I regress current issuance on Wrightson's same-week issuance projection. Next, I estimate an AR(4) in 4-Week issuance sizes via OLS. Last, I include both the Wrigthtson projection and four lags of issuance. The results show three important qualities. First, issuance sizes are fairly persistent, so that a simple AR(4) process has a within-sample R^2 measure of 79%. Second, even given that, the Wrightson projections substantially outperform the simple AR(4), reaching an R^2 measure of 87%. In order words, the Wrightson projections are able to explain 38% of the deviation from the mean issuance size that the AR(4) left unexplained. Finally, lags of issuance offer essentially no predictive power when added to the regression alongside the Wrightson projections.

Table 1: Wrightson In-Sample Predictive Power, Same-Week

	4W Issuance	4W Issuance	4W Issuance
4w Proj	0.94^{***}		0.78^{***}
	$0.9, 1.0$		$0.6, 0.9$
L.4w Iss		1.10^{***}	0.26^{**}
		$1.0, 1.2$	$0.1, 0.5$
L2.4w Iss		-0.24^{***}	-0.07^{*}
		$-0.4, -0.1$	$-0.2, 0.0$
L3.4w Iss		-0.06	-0.07^{*}
		$-0.2, 0.0$	$-0.1, 0.0$
L4.4w Iss		0.05	0.04
		$-0.0, 0.1$	$-0.0, 0.1$
$_{c}ons$	2.33^{***}	5.43^{***}	2.41^{***}
	$1.0, 3.7$	$3.0, 7.9$	$0.8, 4.0$
N	575	575	575
R^2	0.87	0.79	0.87

Note: Shows OLS regression estimates, with the Treasury's weekly realized 4-Week T-bill issuance size as the dependent variable. Independent variables are some combination of Wrightson's same-week projection of the same, and weekly lagged realizations of 4-Week T-bill issuance. Standard errors are heteroskedasticity-robust. Sample is weekly, 2009-2019. Sources: Wrightson ICAP, US Treasury via treasurydirect, and author's calculations.

Wrightson's projections' superior forecasting power is also evident in out-of-sample forecasting exercises. In Table 2 below, I perform such an exercise over the post-crisis sample. In each exercise, at each date in the sample, I form an out-of-sample projection of the following week's 4-Week T-bill issuance via estimating a model using only data available from the previous week. In RW, I assume a random walk in 4-Week T-bill issuances, with the projection for next week's issuance always equaling the previous week's. In AR(4), I estimated an AR(4) in issuance, using data from the previous week and earlier, and use the fitted model to project next week's issuance. In AR(4)+FE, I augment the AR(4) model with week-of-year fixed effects, to capture a degree of seasonality. In Wrightson, the projection of next week's issuance equals Wrightson's same-week forecast. In Wrightson+, I fit an OLS model predicting next week's issuance using Wrightson's projection, four lags of issuance, and four lags of Wrightson's projection errors. The results show that all of the specifications with Wrightson projections as an input have RMSE values substantially lower than the other specifications. Additionally, the out-of-sample forecasting power from taking Wrighton's projections as given (as suggested by theory, if they are indeed rational expectations) is nearly the same as that from using Wrightson's projections as inputs to a linear predictive model.

Table 2: Wrightson Out-of-Sample Predictive Power, Same-Week

Maturity (Weeks)	RW	AR(4)	AR(4)+FE	Wrightson	Wrightson+
4	5.46	5.35	5.21	4.10	4.08
13	1.38	1.46	1.43	1.37	1.39
26	1.45	1.61	1.58	1.31	1.48

Note: Shows root mean squared errors of several out-of-sample forecasting exercises for T-bill issuance, of most regularly-issued maturities. Units on T-bill issuance are in billions of dollars in principal. "RW" projects this week's issuance to be equal to last week's issuance of the same. "AR(4)" and "AR(4)+FE" perform out-of-sample forecasting via an AR(4) in issuance, with or without week-of-year fixed effects to capture a degree of seasonality. "Wrightson" takes Wrightson's same-week projection of issuance as the projection. "Wrightson+" includes Wrightson's same-week projection as one of several independent variables in a regression-based out-of-sample forecast (see text for details). Sample is weekly, from 2009-2019. Sources: Wrightson ICAP via its Money Market Observer publication, US Treasury via treasurydirect, and author's calculations.

There are some modest ways in which the Wrightson projection errors, in my finite sample, behave differently than the rational expectations of theory. Chiefly Table 3 below shows OLS estimates from regressing same-week 4-Week T-bill projection errors on the size of the Wrightson projection itself; lags of projection errors; and lags of 4-Week issuance. In theory, and in a large sample, perfect rational expectation errors should be uncorrelated with any information that should have been known to Wrightson at the time they made their projections. In practice, we find statistically significant positive regression coefficients on the size of the projection, and negative coefficients on the previous week's issuance. This is consistent with there being a modest average tendency, in this sample, for Wrightson to overestimate increases in issuance size from this week to the next.

In light of this evidence, I will conduct robustness checks of the analyses to follow that control for lagged issuance surprises and the size of Wrightson's projection. In practice, I will find that all of the results of this paper are robust to the inclusion of those controls. The R^2 measures from these OLS regressions indicate why. Even though some of the regression coefficients on time-t information are statistically significant, those measures collectively explain only a very small fraction of the variance in the 4-Week issuance surprises themselves. As such, their inclusion as controls has little bearing on the results.

Table 3: Wrightson Autocorrelations

	4W Error	4W Error	4W Error	4W Error
L.4w Error	0.09**	0.11***		0.03
	0.0, 0.2	0.0, 0.2		−0.1, 0.2
L2.4w Error				−0.03
				−0.1, 0.1
L3.4w Error				0.02
				−0.1, 0.1
L4.4w Error				−0.02
				−0.1, 0.1
4w Projection		−0.07***	−0.22***	−0.22**
		−0.1, −0.0	−0.4, −0.1	−0.4, −0.0
L.4w Issuance			0.26**	0.23*
			0.1, 0.5	−0.0, 0.5
L2.4w Issuance			−0.07*	−0.03
			−0.2, 0.0	−0.2, 0.1
L3.4w Issuance			−0.07*	−0.10*
			−0.1, 0.0	−0.2, 0.0
L4.4w Issuance			0.04	0.05
			−0.0, 0.1	−0.0, 0.1
N	575	575	575	575
R^2	0.01	0.04	0.07	0.07

Note: Shows OLS regression estimates with "Wrightson surprises" in 4-Week T-bill issuance as the dependent variable. Independent variables include lags of the same, the Wrightson *projection* of that week's 4-Week T-bill issuance, and lags of 4-Week issuance. Standard errors are heteroskedasticity-robust. Sample is weekly, from 2009-2019. Sources: Wrightson ICAP, via its Money Market Observer newletter, US Treasury via treasurydirect, author's calculations.

Consistent with the exclusion restriction requiring that these surprises be uncorrelated with changes in convenient asset demand conditions, I find that the 4-Week T-bill surprises are uncorrelated with a host of weekly variables that might serve as proxies for convenient asset demand. Those include current and lagged realizations of the VIX index; current and lagged changes in the VIX index; the same for the MOVE interest rate volatility index; and current and lagged log differences in the S&P 500 index. There is some modest serial correlation in the errors themselves, as the previous results suggested.

Table 4: Wrightson Correlations

VIX	0.02
MOVE	0.04
L.4w Error	0.09
S4.VIX	−0.02
L.VIX	0.04
L.S.VIX	0.07
L.MOVE	0.05
S.MOVE	−0.04
S.Log SP 500	0.05
L.S.Log SP 500	−0.08

Note: Shows simple correlation coefficients between Wrightson 4-Week T-bill surprises and other variables of interest. Sample is weekly, 2009-2019. Sources: Wrightson ICAP via its Money Market Observer newsletter, US Treasury via treasurydirect, Federal Reserve Bank of St Louis via FRED.

6.5 Understanding the Shocks

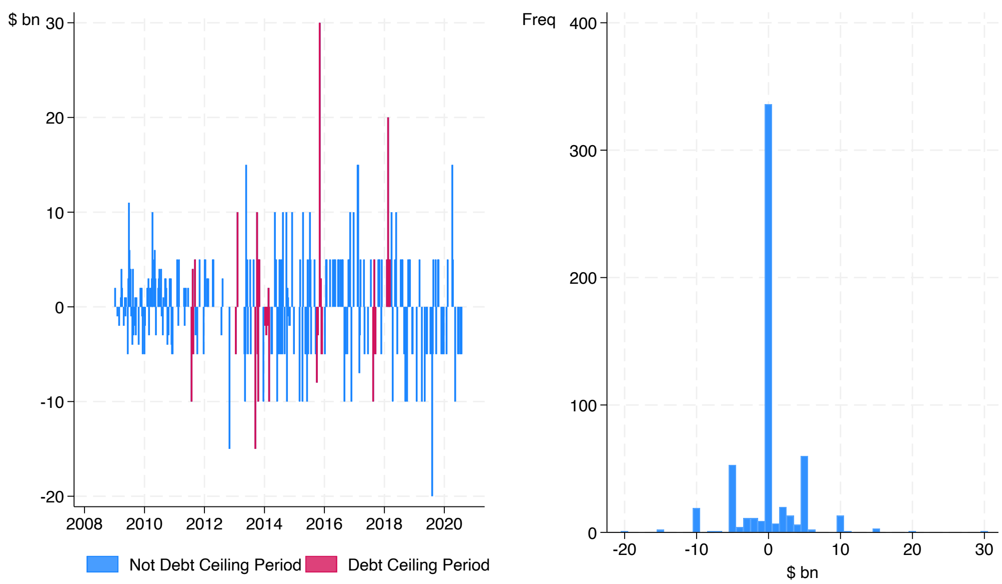
For most of this paper's post-crisis sample, Wrightson projection errors in 4-Week T-bill issuance can be explained as reflecting differences in net cash flow projections between the Treasury and Wrightson. Many of the largest projection errors occur in the months surrounding post-crisis debt ceiling showdowns. During these periods, some surprises are better explained by differences in technical debt management decisions in these periods.

Figure 6 shows my sample of Wrightson issuance surprises in two ways. In the left panel, I show the time series of surprises, split into two subsamples. A "Debt Ceiling Period" is defined as a week within 40 days (either before or after) the final resolution of a debt ceiling episode. The "Not Debt Ceiling Period" subsample includes all other weeks. In the right panel, I show the same data via a histogram, with widths equal to \$1 billion. In both figures, and everywhere in this paper, a surprise is defined as

$$\varepsilon_t^B = \text{Actual 4-Week Bill Issuance}_t - \mathbb{E}_{\text{Wrightson},t-\delta}\left(\text{4-Week Bill Issuance}_t\right)$$

That is, a positive value indicates T-bill issuance that is *greater* (i.e. more borrowing) than Wrightson expected.

Figure 6: Wrightson Surprises, 4-Week T-bill



Note: Time series and histogram of Wrightson surprises, defined in the text as same-week Wrightson projection errors for the 4-Week T-bill issuance size. The left panel shows weekly realizations of this object. The right panel shows a histogram, with bin width of $1 billion. The left panel highlights surprises that occur around debt ceiling reset periods. As described in the text, the underlying *source* of surprises in these periods can differ from those in other weeks. Sources: Wrightson ICAP via its Money Market Observer newsletter, author's calculations.

While the most common outcome is *no* surprise in 4-Week bill issuance, there is still substantial surprise issuance variation over the post-crisis sample. My sample from January 2009 to December 2019 includes 575 weeks of 4-Week bill issuance. Of these, 336 weeks had zero surprise in the 4-Week bill issuance size of that week and 239 weeks had a nonzero surprise. Of 239 surprise weeks, 194 surprises had an absolute value of $5 billion or smaller.

Outside of debt ceiling episodes, Wrightson's discussion of surprises in Treasury's 4-Week T-bill issuance is consistent with the notion that surprises arise from differences between their net cash flow projections and the Treasury's. These discussions are visible in the daily "Treasury Commentary" that Wrightson publishes each morning, in which they sometimes discuss the previous day's developments in fiscal financing. For instance, after October 4th, 2010's +$4 billion surprise, Wrightson writes

> We were surprised by the lack of any increase in the 4-week bills this week, but we were also surprised by a relatively strong Treasury cash balance for Friday...The Treasury's own cash flow forecasts are probably

> slightly more optimistic than ours, as we doubt that the Treasury would cut things quite as close as our current projections imply.

This sort of discussion is not limited to smaller issuance surprises like October 4th 2010's. For instance, after February 13th 2017's +\$15 billion surprise (one of the eight largest surprises in the sample), Wrightson writes

> The Treasury continues to surprise us by not cutting its bill offering sizes more aggressively...The smaller cutbacks in the 4-week bills thus far clearly indicate that the Treasury has a very different near-term cash balance forecast than we do.

In Appendix H, I show empirical evidence consistent with this understanding of the T-bill issuance surprises. Namely, I show that Wrightson T-bill issuance surprises today predict almost-exactly offsetting changes in T-bill supply and net Treasury cash flows over the following weeks. This is consistent with a simple interpretation that the Treasury borrows \$1 billion more over the next several than private agents expect when net outflows are approximately \$1 billion larger than those agents expect.

Wrightson's Treasury commentaries also show that, while not necessarily reflective of the *average* surprise, some of the largest surprises are driven by other, more technical debt management factors. This most commonly occurs around (either before or after) resolutions of debt ceiling episodes, when the Treasury has the widest array of technical concerns to consider, such as the amount of "extraordinary accounting measures" to utilize in order to permit more marketable debt issuance. For instance, after the January 14, 2013 issuance surprise (which was several weeks before the resolution of a debt ceiling episode on February 4, 2013) they write

> The Treasury surprised us by cutting the size of the 4-week bill by \$5 billion, to \$35 billion this week...The unexpected cutback in the 4-week bill presumably reflects an effort to preserve flexibility as debt limit problems approach....There is a lot of uncertainty on two different levels in the outlook. The Treasury's cash flow over the coming weeks will be more difficult to predict than usual due to all of this year's tax changes, and we don't know how much of the Treasury's remaining accounting flexibility is being absorbed by nonmarketable debt issuance to government trust funds.

Indeed, the largest surprise in my sample is a $+\$30 billion$ surprise announced on November 2, 2015. This surprise comes *after* the conclusion of the fall 2015 debt ceiling episode, which effectively resolved when the US House and Senate passed HR1314 on October 30th. Wrightson writes of the surprise

> We had speculated in this week's issue of the Money Market Observer that the Treasury might allow its cash balances to run higher than usual in the months ahead in order to accommodate a more rapid rebound in the supply bills...Of course, the fact that bill supplies would be rebuilt faster than originally expected was old news by the time the Treasury's new quarterly borrowing projections were announced yesterday afternoon, as the Treasury had already announced a startling $45 billion increase in the size of today's 4-week bill auction.

These two debt ceiling-adjacent surprises, which are emblematic of much of the Wrightson discussions around these episodes, show two occassions when a T-bill issuance surprise was driven by technical, debt ceiling-related factors. In the first, Wrightson's and the Treasury's understanding of debt ceiling headroom likely differed – possibly as a result of nonmarketable debt issuance, about which the Treasury could plausibly have superior, private information. In the second, the Treasury decided to increase T-bill supplies more quickly than expected, after a debt ceiling-related low point.

Importantly, in *neither* case does Wrightson give an indication that the reason Treasury's technical decisionmaking differed from expectations was driven by something obviously relevant for *demand*. Surely, new information about the default probability of the US government is revealed during debt ceiling episodes, and that information shifts private demand for T-bills. However, these two episodes (and others around debt ceiling episodes) seem to reflect different debt management decisions, *given* the current state of government default probability. In the second case, for example, all uncertainty about government default was effectively resolved the previous week, when the House and Senate passed the corresponding debt limit increase bill.[31]

7 Core Empirical Results

My local projection estimates suggest that Wrightson T-bill supply surprises have a powerful, but transitory, effect on convenience yields. The convenience yield effect is more transitory than the T-bill supply effect, suggesting that flow effects are stronger than stock effects in this setting. I use the same empirical moments as the local projection approach, with a multi-equation GMM estimation, to estimate these separate flow and stock effects, arriving at this paper's estimate of the long and short-run convenience yield impacts of a T-bill supply change.

[31] It is also worth noting that, in the first of these examples, differences in future projected cash flows may indeed have driven the surprise, as Wrightson discusses "all of this year's tax changes" creating cash flow uncertainty.

7.1 Methodology

I first provide additional details about how the LP-IV setup introduced in Section 6.1 will be used in this setting, to estimate impulse responses to T-bill supply shocks. I then detail how I use the simple structure of Equation (3) and the shape of those impulse responses to estimate separate stock and flow effects.

In this section, I estimate impulse response functions to a T-bill supply surprise. I do this via a 2SLS, LP-IV specifications of the form

$$\text{2nd: } Y_{t+h} = \alpha_{2,h} + \gamma_h \frac{B_t}{GDP_t} + \phi'_{2,h} X_{t-\delta} + e_{t+h} \tag{9}$$

$$\text{1st: } \frac{B_t}{GDP_t} = \alpha_1 + \chi \varepsilon_t^B + \phi'_{1,h} X_{t-\delta} + w_t \tag{10}$$

where $\frac{B_t}{GDP_t}$ is T-bill supply as a percentage of GDP; ε_t^B is the Wrightson T-bill supply surprise variable; and $X_{t-\delta}$ is a list of control variables. The lefthand side variable Y indicates some dependent variable of interest. In this section, Y is either a measure of the T-bill convenience yield, or a measure of T-bill supply. The time indices in equations (9) and (10) indicate weeks.

The vector of control variables $X_{t-\delta}$ will vary across specifications, but will only ever include objects which should be publicly known and observable prior to the realization of the shock ε_t^B. The time subscripting $t - \delta$ is meant to signify this. In all specifications, $X_{t-\delta}$ will include lags of the dependent variable of interest Y, so that our impulse response estimates are estimated with high frequency variation in Y alone. When estimating the response of a variable that varies at the daily frequency, $X_{t-\delta}$ will include lagged daily observations for Y in the days before the T-bill auction announcement when ε_t^B becomes observed. While $X_{t-\delta}$ does not include lagged realizations of the T-bill surprise in the baseline specification, robustness results in Appendix J do. Their inclusion has no material impact on the results. The vector $X_{t-\delta}$ also includes Wrightson's expected future T-bill supply in each of the following 6 weeks. These are expectations formed before the realization of the surprise in time t.

After presenting these results, I will use the same empirical moments to estimate the parameters β and $\beta(\frac{1}{\mu} - 1)$ via GMM, by imposing the simple dynamics implied by equation (3). To do this, I construct moment conditions of the form

$$\mathbb{E}\left(e_{t+h} X_{t-\delta}\right) = 0 \tag{11}$$

$$\mathbb{E}\left(e_{t+h} \varepsilon_t^B\right) = 0 \tag{12}$$

$$\tag{13}$$

where

$$e_{t+h} = \frac{i_{t+h} - i^B_{t+h}}{1 + i_{t+h}} - (\alpha_{2,h} + \phi'_{2,h} X_{t-\delta} - \frac{\beta}{\mu} \Delta \frac{B_{t+h}}{GDP_{t+h}} - \beta \frac{B_{t+h}}{GDP_{t+h}})$$

for $h \in \{0, 1, 2, \cdots, H\}$. In my baseline application, $H = 9$. These moment conditions are constructed so that the structural GMM estimation and the reduced form LP-IV approach are estimated using the same moments in the data. The difference between the two approaches is that the GMM estimation will require the shapes of the estimated responses of T-bill supply B_{t+h} and convenience yields to be related via the estimated parameters β and $\frac{\beta}{\mu}$. As I will show below, this imposed structure allows a good fit.

When $h \geq 1$, this estimation is overidentified. In the GMM procedure, I perform a two-step, optimal GMM estimation using a Newey-West, autocorrelation-consistent approach to estimate the variance of the estimated moment conditions. Results are similar when I instead use a one-step GMM approach, with moment conditions weighted by the identity matrix.

While this approach seems like a natural way to estimate separate flow and stock effects using these shocks and data, I note that the LP-IV estimates themselves are more robust to model misspecification than the structural GMM approach that follows. LP-IV estimates in this setting will be consistent estimates of the true underlying impulse response function, provided that the Wrightson surprises are uncorrelated with other shocks to convenient asset demand over the impulse horizons. To interpret the GMM estimates as structural, we must also assume that the convenience yield response operate strictly through the channel that Equation (3) allows – namely, the contemporaneous stock and flow of T-bill supply.

7.2 LP-IV Results: Future Quantity

In order to interpret the convenience yield impulse response estimates to follow, we must first understand how a Wrightson surprise predicts both levels and changes of future T-bill supply over the response horizon. These results show that the response of T-bill supply rises for several weeks, before falling back to its pre-surprise level.

To reach these estimates, I estimate equations (9) and (10) by 2SLS, replacing Y with $\frac{\text{Bills}}{\text{GDP}}$. The results are shown in Figure 7 below. I depict 90% confidence intervals along with the point estimates. Given recent results from Olea and Plagborg-Møller (2021) that simple, heteroskedasticity-robust standard errors are sufficient in local projection settings such as this, the standard errors shown here are heteroskedasticity robust. I have found that including Newey-West, autocorrelation-consistent standard errors instead tends to *shrink* the estimated confidence intervals, making this choice conservative.

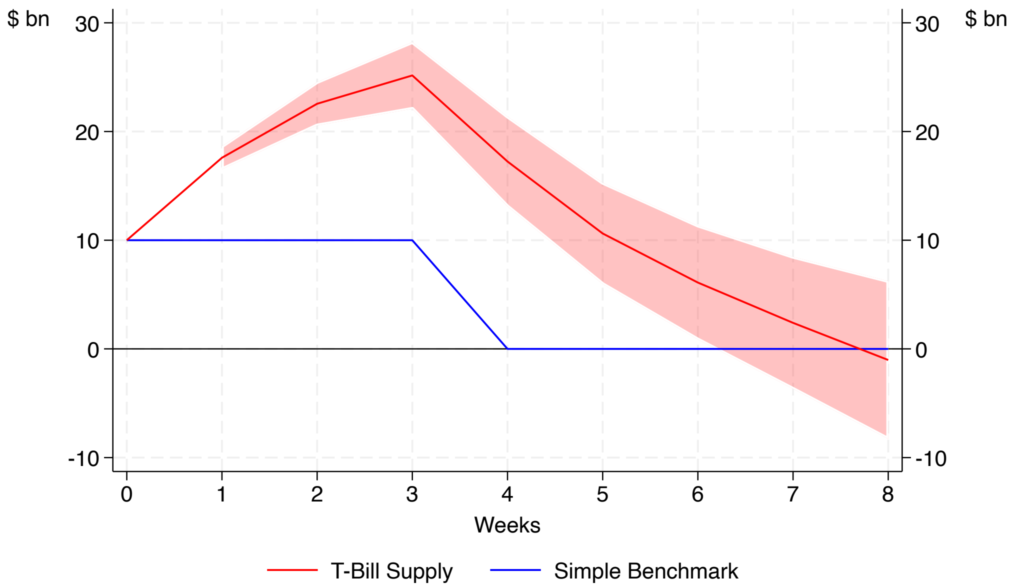
Figure 7 shows a hypothetical "Benchmark" impulse response, which is the response we would see if a 4-Week Wrightson T-bill surprise in week 0 predicted *no* other changes in Treasury issuance over the response horizon. A 4-Week bill contributes positively to total T-bill supply for four weeks. After that point, the bill matures and leaves the outstanding stock.

An impulse response function like this "Simple Benchmark" is resoundingly rejected by the data. Instead, this response suggests that a positive $10 billion surprise in T-bill issuance today predicts additional increases in T-bill supply for the next several weeks. Like in the "Simple Benchmark", supply tends to begin falling at week 4, when 4-Week bills issued in week 0 mature. At its peak in week 3, the T-bill supply response is $25 billion.[32]

We can understand this result by recalling the Treasury's stated objective of "regular and predictable" issuance. In a world where the Treasury wishes to keep T-bill issuance predictable, but where unexpected cash flow needs necessitate occasionally surprising market participants, the Treasury should attempt to *smooth* the effect of unexpected cash flows on T-bill issuance. Doing so would tend to lead to smaller issuance surprises, week-to-week.

[32]In this impulse response and all of those to follow, the initial shock is normalized to raise T-bill supply by $10 billion this week. As is standard in this literature, the underlying estimation normalizes T-bill supplies by then-current nominal GDP. I report values in billions of dollars by converting the empirical estimates to dollars, using nominal GDP for 2017Q1.

Figure 7: Impulse Response of Future T-bill Supply to T-bill Issuance Surprise



Note: Shows estimate impulse response function of future T-bill supply to a T-bill supply shock in period 0, defined as a Wrightson surprise that elevates period 0 T-bill supplies by $10 billion. Estimates and standard errors computed via LP-IV, as described in the text. Confidence bands are 90%, computed via heteroskedasticity-robust standard errors. "Simple Benchmark" line depicts the hypothetical response one would expect, if a Wrightson surprise in period 0 predicted no other changes in T-bill issuance over the horizon. Sources: Wrightson ICAP via its Money Market Observer Newsletter, US Treasury via treasurydirect, author's calculations.

7.3 LP-IV Results: T-bill Convenience Yields

I now turn to the principle empirical result of this paper, and estimate the convenience yield response to a T-bill supply shock. The response of T-bill convenience yields to a surprise T-bill issuance is large and statistically significant in the first weeks following the surprise. However, the convenience yield response decays to zero much sooner than T-bill supply itself returns to zero. Indeed, convenience yields four weeks after the initial shock are modestly *larger* four weeks after the initial surprise, even though T-bill supply is still substantially elevated at this time.

A T-bill issuance surprise creates a large and statistically significant response in the convenience yield in the weeks after the shock. These results are shown in Figure 8. At the time of issuance, a $10 billion T-bill surprise comes with a 0.82bp decline in the size of the convenience yield.

In the most-recent estimate in the literature with a similar sample period, D'Avernas and Vandeweyer (2022) report that a $100 billion increase in T-bill supply depresses T-bill convenience yields by 4bp. That study, which does not use an impulse response framework, does not differentiate between the short and long-run convenience yield response. For ease of comparing my estimates to the literature, I include in Figure 8 a "Benchmark" line, which applies the most-natural interpretation of those earlier results to construct a hypothetical T-bill convenience yield impulse response. This green line is equal to 0.04bp, multiplied by the then-current realization of the impulse response for T-bill supply to the shock. As Figure 8 shows, my point estimate for the on-impact response of convenience yields is over twice as large as that benchmark result would suggest.

The shape of the rest of the impulse response function supports the notion that the short-run impact of a change in T-bill supply is much larger than the long-run impact. In addition to giving a sense of the magnitude of my results, the "Benchmark" line also shows the shape of the impulse response that we would expect, if the then-current outstanding stock of T-bills is the most important determinant of the convenience yield. That is not what the estimates suggest. Rather, we see the peak response at week 1 – not at week three, when the stock of T-bills is at its highest point.

Indeed, the point estimate for the convenience yield response is positive for several weeks, beginning in week 4. Note also from the Figure that, at week 4, T-bill supplies are still well-elevated, relative to their level before the surprise. The assumed structural equation (3) has no difficulty explaining this response. In week 4, T-bill supply begins to fall, even though the stock is still elevated. If flow effects are much stronger than stock effects, then a positive convenience yield response at those horizons could well result.[33]

Figure 8 summarizes my principal empirical result, which the rest of this paper will work to better understand - that T-bill supply shocks appear to have a transitory effect that is substantially greater than the the long-term effect that these impulse responses allow. The GMM estimation that follows formalizes this intuition, and delivers conclusions about the permissible sizes of any long-run supply effect, to be consistent with these impulse responses.

[33]Nonetheless, it is worth noting what sorts of market frictions might cause this type of response. This sort of effect sees most-consistent with a model where T-bill investors view a rollover of their maturing T-bill holdings into the newest issues as less costly than moving their capital into some alternate investment.

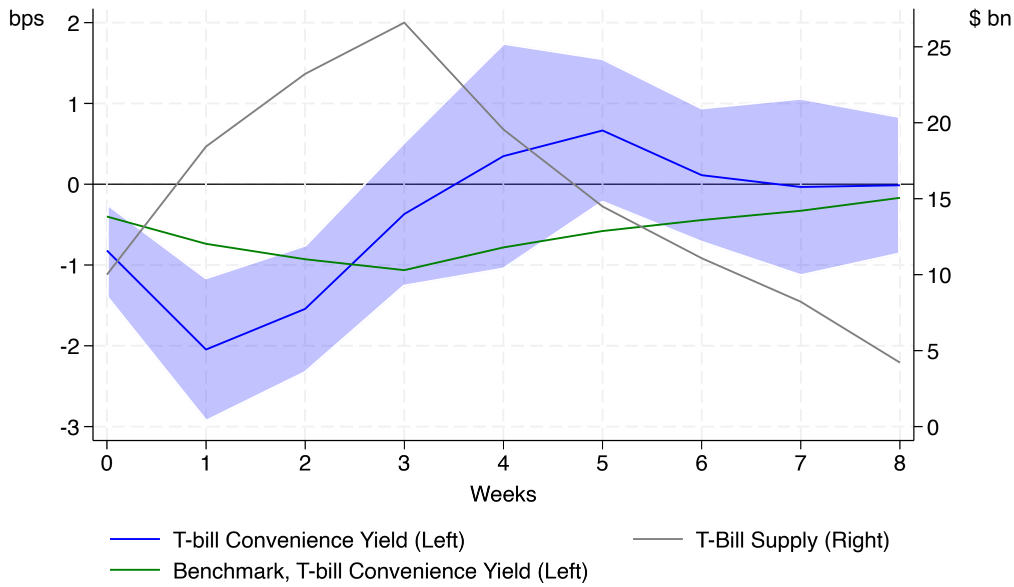


Figure 8: Impulse Response of T-bill Convenience Yield

Note: Show estimated impulse response function of 4-Week T-bill convenience yields to a T-bill supply shock, defined as a week 0 Wrightson surprise. Results are estimated via LP-IV. Confidence bands are 90% and standard errors are heteroskedasticity-robust. "T-bill supply" line depicts the same impulse response as Figure 7, for reference. "Benchmark" shows impulse response one would expect, if T-bill supply changes move convenience yields immediately and permanently by 0.4bp / $10bn, in line with an estimate from D'Avernas and Vandeweyer (2022). Sources: Wrightson ICAP via its Money Market Observer newsletter, Bloomberg, Federal Reserve Board of Governors via its H15 release, author's calculations.

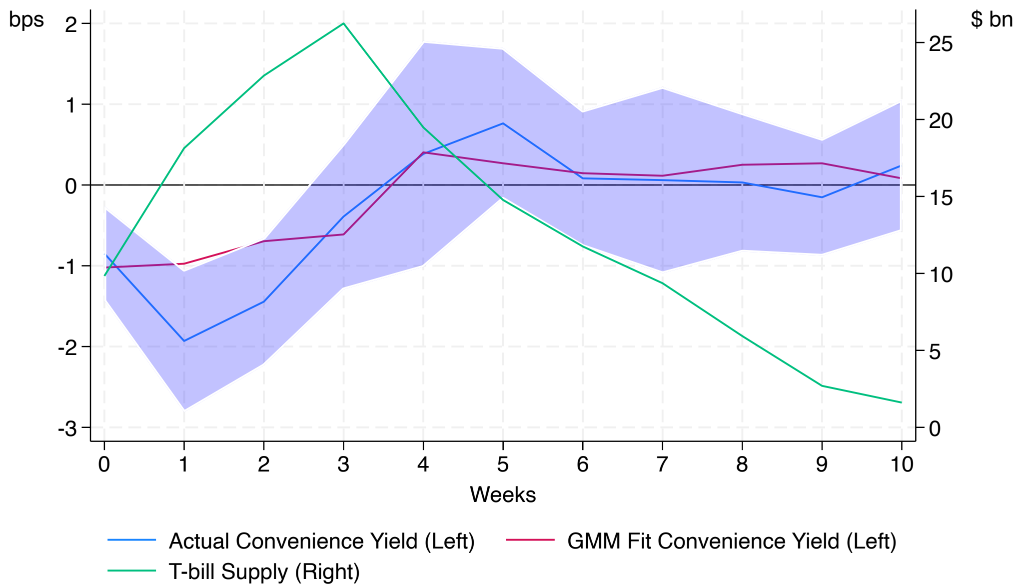
7.4 GMM Results

I use the moments from the LP-IV setup above to estimate separate flow and stock effects via GMM, as described in Section 7.1. I estimate that the same-week effect of an increase in T-bill supplies of $100 billion depresses convenience yields by 10.4bps. I estimate a long-run effect of only 1.1bps/$100 billion, with a tight enough confidence band to reject long-term effects larger than 3.0bps/$100 billion.

Figure 9 below shows the fit of the structural estimates in describing the shape of the LP-IV impulse response. The blue line of the figure reproduces the convenience yield impulse response in Figure 8. This is an *unrestricted* estimated fit for the impulse response, in the sense that a separate estimate of $\hat{\beta}_h$ is estimated, to fit each horizon h. The red line in Figure 9 uses the estimated impulse response for T-bill supply; my estimate of the flow effect; and my estimate of stock effect to describe the impulse response. This is a *restricted* estimate for the impulse response.

The close similarity between the blue line of Figure 9 and the red line representing the GMM fit show that the fit is quite good. In other words, imposing the structure of Equation (3) sacrifices little information, compared to the unrestricted LP-IV estimate, so that my two estimates of the flow and stock effect are an effective way of summarizing the dynamics suggested by the response. As another assessment of model fit, I am unable to reject the null hypotheses that all of the moment conditions are true. That chi-squared hypothesis test carries a p-value of 0.24. This test is possible because the GMM model is overidentified.

Figure 9: GMM Model Fit to LP-IV Moments

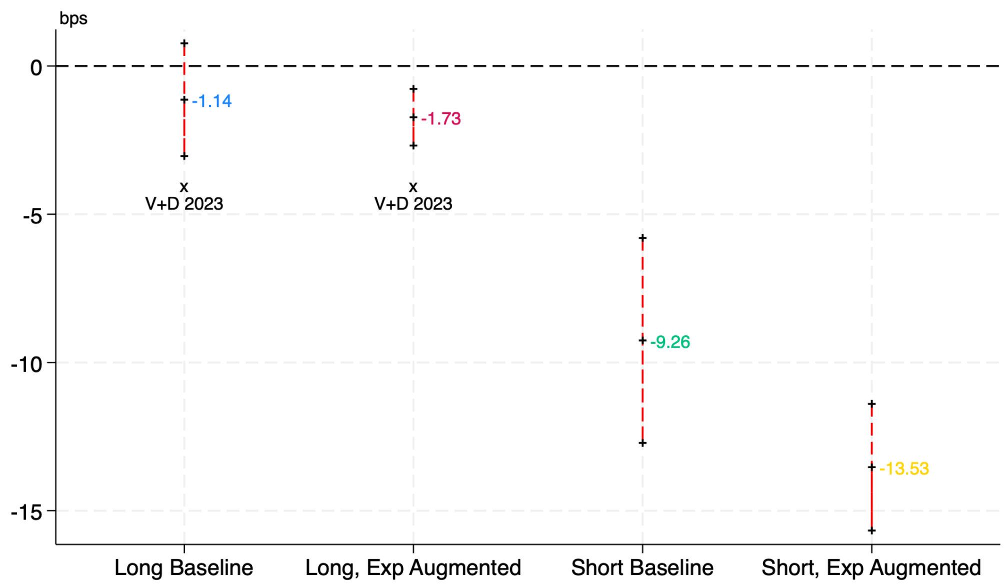


Note: The red line shows the two-parameter GMM fit of the empirical moments from the LP-IV estimates depicted in Figure 8, as described in the text. The blue and green lines shown are the same as in that figure. Sources: Wrightson ICAP via its Money Market Observer newsletter, Bloomberg, Federal Reserve Board of Governors via its H15 release, author's calculations.

The GMM procedure produces estimates of the stock effect that are small and estimates of a flow effect that are large. The point estimate for β, the stock effect in the notation of equation (3), is -1.14bp / \$100 billion. The point estimate for the flow effect is -9.25bp / \$100 billion.

In Figure 10, the point estimate and 90% confidence interval for the stock effect is shown as "Long Baseline". The point estimate and associated confidence interval of the flow effect – $\beta(\frac{1}{\mu-1})$ in Equation (3) – is shown as "Short Baseline". The D'Avernas and Vandeweyer (2022) estimate of -4bp/\$100 billion is show as a black "x", under the confidence interval of the "Long" effect. The means that my point estimates can reject a stock effect of -4bp / \$100 billion.

Figure 10: Point Estimates for "Short" and "Long" Convenience Yield Effect



Note: "Baseline" estimates shows the point estimates and confidence intervals for the flow and stock effects underlying the fit in Figure 9. The "Exp Augmented" results show flow and stock effects for the power-preserving specification described in section 7.5. Confidence bands are 90%. Standard errors are calculated via standard, GMM delta-method approaches, with a Newey-West, autocorrelation-consistent kernel for the moment covariance matrix. Sources: Wrightson ICAP via its Money Market Observer newsletter, Bloomberg, Federal Reserve Board of Governors via its H15 release, author's calculations.

Some readers may be skeptical of the fit shown in Figure 9, because the *fitted* impulse response at week 1 lies just outside of the 90% confidence interval of the LP-IV estimate. That point in the impulse response is indeed the most challenging for the GMM procedure to fit. Given that the *change* in T-bill supply from week 0 to week 1 is approximately the same as the change from week 1 to week 2, estimating large flow effects and small stock effects suggests that the convenience yield response at those two horizons should be nearly the same. Instead, the LP-IV estimates suggest that the convenience yield response at week 1 is larger.

There are modest ways to alter the GMM procedure, which produce better fits at those shorter horizons, such that the fitted response fits within the LP-IV confidence intervals. Doing so produces only modestly different estimates of the stock the flow effects. In Appendix E, I show results for a one-step GMM procedure, with a GMM weight matrix equal to the identity matrix. Estimates with pre-specified weight matrices are asymptotically inefficient, but still consistent. That weight matrix only modestly increases my estimate of the "stock" effect, to 1.85 bp/$100 billion.

7.5 An Alternate, Power-Preserving GMM Procedure

Next, I propose and estimate an alternate version of the GMM estimation above, which leverages the rich, high-frequency nature of Wrightson's projections data to obtain more power in the estimation. This procedure has a stronger exclusion restriction than the estimates above, but yields substantially smaller standard errors. Under this power-preserving estimation, the "stock" effect estimated above becomes statistically significantly different from zero, at the 10% level.

While the estimation procedure above uses fairly standard local projection techniques, in some ways it does not fully take advantage of the richness of the Wrightson T-bill projections. The LP-IV approach above (and the GMM estimation that uses the same moments) estimates the average convenience yield response after a Wrightson supply shock, and relates that to the average T-bill supply response after those same shocks. Figure 7 shows that this average response is a semi-persistent, but not permanent, T-bill supply change that rises for several weeks, then falls.

However, my setting is unusual in that I can measure how projections of future T-bill supply have changed fairly soon after each measured surprise. Using this information, I can supplement the GMM estimation above with another source of variation, that accounts for Wrightson's own expectations of how persistent the supply change from each supply will be. That is, I can supplement the moment conditions in equations (11) and (12) with an additional set of moments, corresponding to a new set of instruments:

$$\mathbb{E}\left(e_{t+h}\text{Update}_{t,t+h}\right) = 0$$
$$\mathbb{E}\left(e_{t+h}\text{Update}_{t,t+h-1}\right) = 0$$

$$\text{Update}_{t,t+h} = \left(\mathbb{E}_{Wrightson,t+1-\delta}B_{t+h} - \mathbb{E}_{Wrightson,t-\delta}B_{t+h}\right) \times \mathbf{1}\left(\varepsilon_t^B \neq 0\right)$$

That is, I use Wrightson's projection *updates* for future T-bill supplies at each future horizon as additional instruments for T-bill supply levels and changes at those horizons. These new instruments are the change in projections that Wrightson reports between their pre-surprise projections and their first post-surprise projection (i.e. the following Monday morning). I interact this update variable with dummy that equals 1 when week t had a nonzero Wrightson T-bill surprise. This limits the update variable to those information updates that could plausibly be driven by information revealed in a 4-Week T-bill surprise.

The exclusion restriction for using this extra dimension of variation is stronger than that from earlier specifications. First, these new instruments inherently compare surprises that are expected to be persistent to those that are expected to be more transitory. To use this variation for identification, it must be the case that convenient asset *demand* is not systematically different between states where a surprises' effects are perceived to be permanent. Second, this approach sacrifices some of the desirable ways in which identification strategy resembles high frequency identification methods in the empirical macroeconomics literature. Because Wrightson does not publish updated projections *immediately* after a 4-Week T-bill supply surprise, this measure of projection updates is necessarily taken as of several days after the associated surprise. It is conceivable that there is additional information, beyond the surprise directly measured via ε_t^B that is included in my measurement of the projection update.

That said, there are some ways in which these additional assumptions are not overly restrictive. The identification logic of Section 6.2 is that the Treasury does not change its issuance strategy in response to short-term fluctuations in demand. It seems plausible that this means *updates* to Wrightson's future T-bill supply projections in week 0 should not be directly affected by short-term fluctuations in demand. Arguing that *surprises* in week 0 are unrelated to demand is conceptually similar to arguing that updates to T-bill projections in week 0 are unrelated to demand.

GMM estimates using this alternate set of instruments are also presented in Figure 10. Point estimates for the stock effect are listed as "Long, Exp Augment". Point estimates for flow effect are listed as "Short, Exp Augmented". Estimates for both the flow effect and stock effect are somewhat larger, moving to 13.53bps/\$100 billion and 1.73bp/\$100 billion, respectively. Consistent with this new approach using additional T-bill variation ignored by the earlier estimates, the confidence bands are substantially smaller. Under this alternate estimation, the estimated stock effects are statistically significantly different from zero, at all conventional confidence levels.

8 Empirical Results, Convenient Asset Substitutes

I show several estimates in support of the assumptions about convenient asset substitutes that were made in Section 5. First, I show that issuance volumes of FHLB discount notes do fall after a T-bill supply shock, but not by amounts that are large enough to materially impact my estimates for β. Next I show that, as expected, the convenience yield effect of T-bill supply shocks in periods when the ONRRP is *active* is smaller than in the inactive period, used in the results above. I find that repurchase agreement volumes falls substantially in the period when ONRRP is active, as the stylized framework in Section 5 describes.

I first assess whether rate sensitivity in the issuance of short-term Federal Government Agency notes is quantitatively large enough to meaningfully affect my estimates of β, in the manner discussed in Section 5.2. To do this, I estimate the impulse response of four-week discount note issuance by the Federal Home Loan Bank system, via LP-IV with

$$\text{2nd: } \sum_{\ell=0}^{3} \text{4W FHLB Issuance}_{t+h-\ell} = \alpha_{2,h} + \gamma_h B_t + \phi'_{2,h} X_{t-\delta} + e_{t+h} \tag{14}$$

$$\text{1st: } B_t = \alpha_1 + \chi \varepsilon_t^B + \phi'_{1,h} X_{t-\delta} + w_t \tag{15}$$

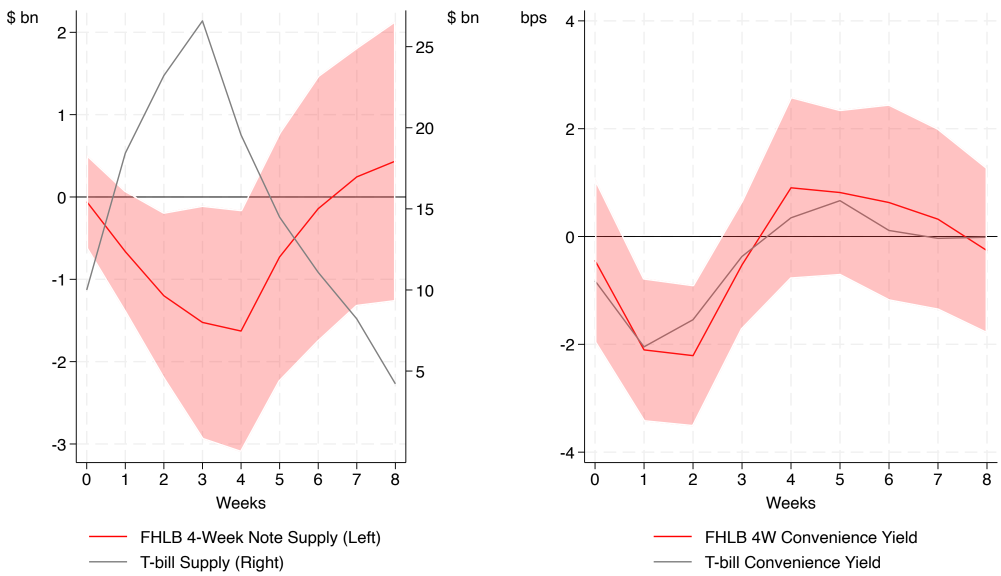
The 4-week moving sum on the lefthand side of the second stage regression reflects the fact that I am most interested in the impulse response of then-current FHLB discount note *supply* (i.e. stock). FHLB issuance data is a flow that requires some empirical assumptions to be used in this manner.

Figure 11 shows these results in the left panel. The direction of the response of FHLB discount note volumes moves in the expected direction, so that a surprise increase in T-bill supplies decreases FHLB discount note supplies over time. The response is statistically significant after the first week, for several weeks thereafter.

The results of Figure 11 show that the likely magnitudes of the response of FHLB issuance is not large enough to substantively alter my estimates of β. That is, in the notation of Section 5.2, $\frac{d\text{Agency}_t}{d\text{Bills}_t}$ appears small. A T-bill supply surprise that causes \$23 billion of additional T-bill supply after 3 weeks causes a peak decrease in FHLB supply of only approximately \$1.5 billion.[34]

[34] The fact that this analysis is restricted to FHLB discount notes is not very restrictive. The FHLB system issues the vast majority of short-term discount notes issued by any non-Treasury US government agency. In August 2023, Fannie Mae had \$15.23 billion of discount notes outstanding. Freddie Mac had \$5.6 billion of discount notes outstanding. In June 2023, the FHLB system had \$321 billion of discount notes outstanding.

Figure 11: Impulse Response of FHLB Note Convenience Yields and Issuance Volumes



Note: Shows estimated impulse responses for convenience yields and issuance volumes of 4-Week discount notes issued by the FHLB – a commonly-discussed substitute for T-bills, for many market participants. Confidence intervals are 90% and standard errors are heteroskedasticity-robust. Sources: Wrightson ICAP via its Money Market Observer newsletter, Bloomberg, Federal Reserve Board of Governors via its H15 release, Federal Home Loan Banks system via its released auctions data, author's calculations.

The right panel of Figure 11 also shows the impulse response function of FHLB convenience yields to a Wrightson T-bill surprise. Reassuringly, this impulse response function looks nearly identical to the T-bill convenience yield response featured above. This shows that that the results above also affect the rates of the likely closest T-bill substitutes.

Next, I assess the extent to which movements in repo volumes might affect our estimates of β. In principle, we might conduct the same analyses as in Figure 11, for repo convenience yields and repo volumes. In practice, this is complicated by a lack of appropriate, high frequency repo volume data for my entire post-crisis sample. The US repo market is composed of many subsectors, which are used by their participants for different reasons. I am most concerned with the repo market subsector that is used by cash investors (like money market mutual funds) to invest principle. Cash investors in these subsectors are the most likely investors to view T-bills and repurchase agreements as substitutes. The largest repo subsectors that fit this criteria are the Federal Reserve's ONRRP facility and the tri-party repo market. High frequency data on tri-party repo volumes became publicly available in September 2014.

I proceed by estimating impulse response functions for repo volumes and repo convenience yields by subsample, estimating separately for the ONRRP$= 0$ and ONRRP > 0 subsamples.[35] To do this, I define the repo convenience yield as $\text{IOER}_t - \text{Repo Rate}_t$, where IOER is the interest on excess reserves set by the Federal Reserve. Repo Rate is the triparty repurchase agreement repo rate reported by the Federal Reserve Bank of New York.[36]

These estimated impulse responses are shown in Figure 12. These results are largely consistent with the stylized story of Section 5. When volume at the ONRRP is strictly positive, repo volume is the margin of adjustment to a T-bill supply shock. The red line in the right panel of Figure 12 shows that repo volumes decline after a T-bill issuance shock, in a statistically significant way. Moreover, the volume of the decline is similar to the increase in T-bill volume after a shock. This suggests that repo volumes decrease after a T-bill supply shock in this subperiod nearly 1-for-1. Also consistent with this story, the impulse response of repo convenience yields is close to flat over this period. When ONRRP $= 0$, the repo convenience yield adjust substantially (and in the theoretically expected direction) after a T-bill supply shock.

An interesting and potentially surprising result is that the blue line in the right panel of Figure 12 is relatively flat and statistically indistinguishable from zero. This suggests that while repurchase agreement volumes respond *substantially* to T-bill supply shocks in the ONRRP > 0 period, they do not appear to respond nearly as strongly in the ONRRP $= 0$ subperiod.[37] Returning to the stylized examples of Figure 4, this suggests that the bottom-right panel is a reasonable representation of reality in the ONRRP $= 0$ period. That is, private repo supply curves are sufficiently inelastic that $\frac{dRP_t}{d\text{Bills}_t} \approx 0$.

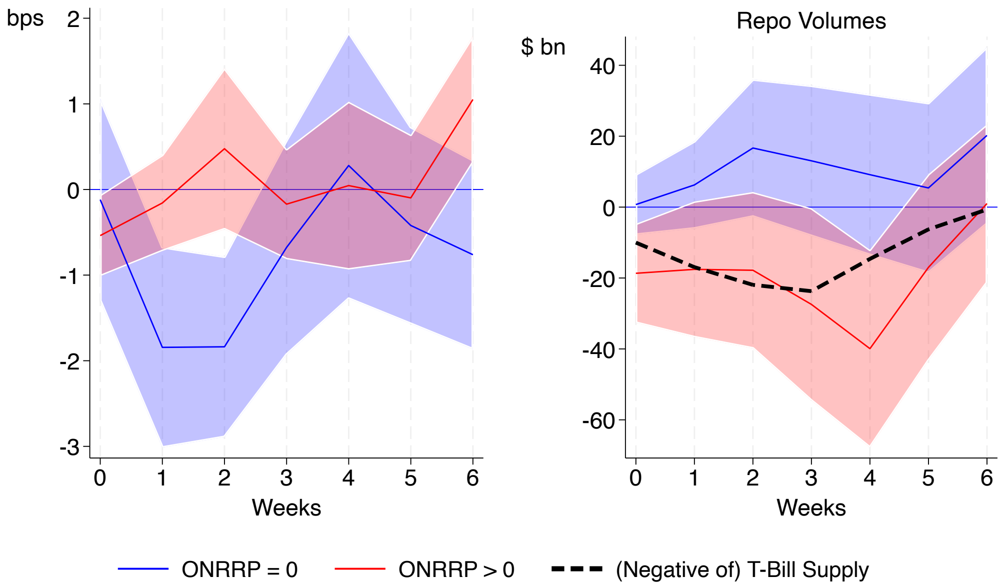
This suggests that the structural estimates of flow and stock effects from the ONRRP$= 0$ subsample should reflect the T-bill convenience yield response to T-bill supply shocks with only little response in the supply of non-Treasury substitutes. That is, the impulse response of T-bill supplies in this subsample is a good proxy for the impulse response of *total* safe asset supplies. This is the assumption that motivated focusing my attention in the preceding analyses to changes in T-bill supply.

[35] These estimating equations are the natural analog of equations (14) and (15), adapted to these new lefthand side variables.

[36] In the early subsample, this rate is a survey rate reported by the largest dealers participating in this market. Later in the subsample, I use the Treasury Triparty general collateral rate reported by FRBNY.

[37] Indeed, the point estimate is positive, which is of a theoretically unexpected sign.

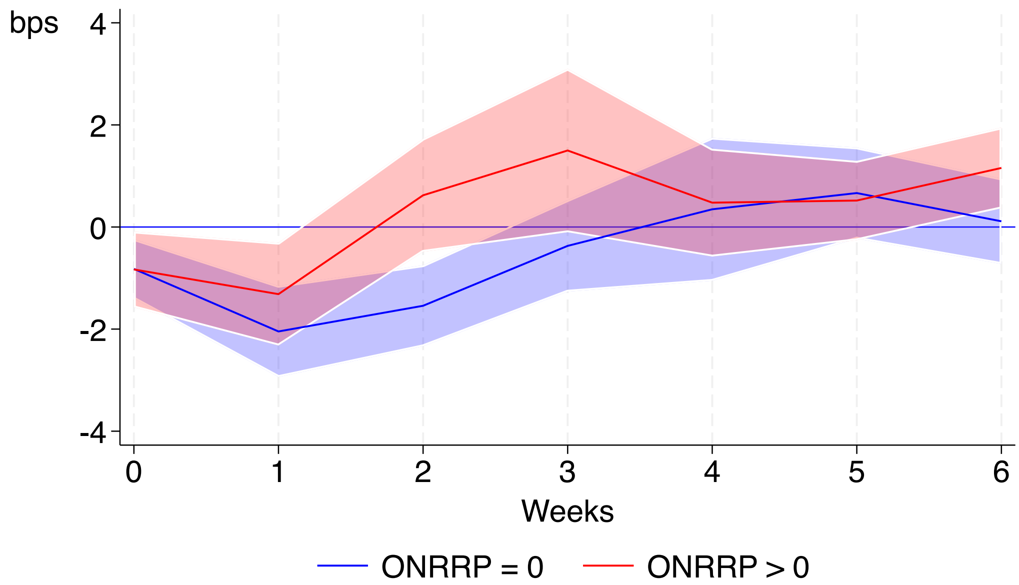
Figure 12: Impulse Response of Repo Convenience Yields and Repo Volumes



Note: Shows estimated impulse response functions for repo volumes and repo "convenience yields" to a T-bill supply shock, defined as a week 0 Wrightson surprise. Repo volumes are defined as the sum of private tri-party general collateral repo volumes as reported by the OFR, and ONRRP takeup as reported by FRBNY. Repo convenience yields are the difference between the interest on excess reserves and then-current, representative repo rates. When available, the repo rate used is the broad general collateral repo rate reported by FRBNY, When not available, it is the general collateral repo survey rate reported by the same. Sources: Wrightson ICAP via its Money Market Observer newsletter, Federal Reserve Board of Governors via its H15 release, FRBNY via its published repo rates and volumes, Treasury OFR via its repo market data release, author's calculations.

Lastly, Figure 13 shows that T-bill convenience yields do indeed less in the ONRRP>0 period. While point estimates at week 0 are nearly the same as in the ONRRP≈ 0 period, estimates in the following weeks are smaller. These indicate a smaller, and less persistent, convenience yield response when takeup volume at the ONRRP is an available margin for market adjustment.

Figure 13: Impulse Response of T-bill Convenience Yields by Subsample



Note: Compares estimated T-bill convenience yield impulse responses, to a T-bill supply shock, in subperiods where ONRRP takeup is close to zero or substantially positive. Confidence intervals are 90% and standard errors are heteroskedasticity-robust. Sources: Wrightson ICAP via its Money Market Observer newsletter, Federal Reserve Board of Governors via its H15 report, author's calculations.

9 Application: $R < G$ and Debt Sustainability

To place my core empirical results in context, and demonstrate how they will tend to impact the quantitative conclusions of macroeconomic models featuring public debt convenience yields, I replicate a calibration exercise from Mian et al. (2022) on fiscal sustainability when $R < G$, using my estimates of a substantially flatter long-run convenient asset demand curve. My estimates suggest that endogeneity of convenience yields is not a strong enough force to meaningfully constrain the implications of Blanchard (2019), that large fiscal deficits appear sustainable when $R < G$.

The model of Mian et al. (2022) offers an excellent setting to understand the positive, quantitative impact of my results for fiscal sustainability in a transparent, minimalist setting. With those goals in mind, I present the simplest, most-stylized form of their model, without considering complications created by the zero lower bound, or aggregate risk. In this section, I summarize the components of that model which are most important for understanding its conclusions about the importance of the slope of the convenient asset demand curve. In Appendix **??**, I describe the model in greater detail. Given that this section has the goal of applying the Mian et al. (2022) model as closely as possible, that discussion is naturally very similar to the original authors'.

The model is deterministic and exists in continuous time. It features households, which are separated into populations of savers and spenders. Savers have the ability to save via holdings of government debt, for which they enjoy flow convenience benefits in addition to the security's interest payments, as in Section 3. The model features a central bank which, in this simplest form of the model, is able to perfectly maintain its inflation target by keeping interest rates at the natural rate.

A government in the model sets fiscal policy via its choice of government spending x, borrowing b_t, and lump-sum taxes on savers τ_t. Its choices must satisfy the flow budget constraint

$$\frac{db_t}{dt} = z_t + R_t b_t$$

where z_t is the primary fiscal deficit, such that $z_t = x - \tau_t$. R_t is the nominal interest rate on government debt, and $\dot{b}_t$ is net government borrowing in moment t. R_t is the nominal interest rate on government debt.

This is a model about maintaining a stable *ratio* of government debt to GDP y_t. As such, it is convenient to redefine $\tilde{h}_t = \frac{h_t}{y_t}$, and rewrite this flow budget constraint as

$$\frac{d\tilde{b}_t}{dt} = \tilde{z}_t + \tilde{b}_t \left(R_t - G\right)$$

where G is the growth rate of nominal GDP. In the version of the model without a ZLB, where the central bank is always able to keep output at potential, this is the same as normalizing by potential GDP, which the authors do in their own presentation.

The Euler equation of the saver households in the model is

$$\frac{d\log(\tilde{c}_t)}{dt} = R_t - G - \rho + v'(\tilde{b}_t)\tilde{c}_t \tag{16}$$

where ρ is the (continuous time) discount rate, and $v'(\cdot)$ is the marginal extrapecuniary value of convenience from public debt.

Considering a steady state in a detrended model where potential output is constant, the natural rate R^* is the rate that supports constant consumption by savers in Equation (16). When government debt b is constant in steady state, this gives

$$R^*(\tilde{b}) = \rho + G - v'(\tilde{b})\tilde{c}_s$$

where $\tilde{c}_s$ is the steady state consumption of savers. In the model, this equals $1 - \mu - x$, where $1 - \mu$ is the labor endowment of savers.

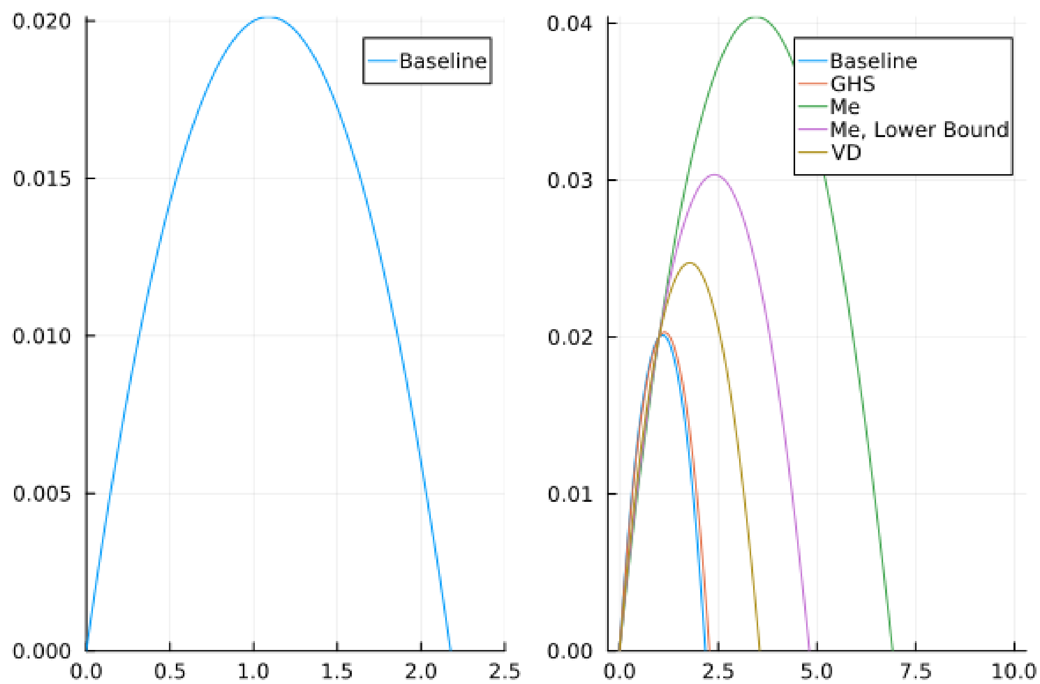
Continuing to consider a steady state where consumptions and government debt are constant, the government's flow budget constraint suggests

$$z(\tilde{b}) = (G - R^*(\tilde{b}))\tilde{b} \tag{17}$$

where $z(b)$ is the primary deficit (as a share of GDP) that supports the steady-state level of debt-to-GDP $\tilde{b}$.

Equation (17) characterizes the model's useful deficit-debt diagram. This diagram characterizes the relationship between steady state levels of the primary deficit $\tilde{z}$ and level of government debt $\tilde{b}$. The left-hand panel of Figure 14 shows the deficit-debt diagram for the baseline parameters in the calibration exercise of Mian et al. (2022).

Figure 14: Deficit-Debt Diagrams, Under Alternate Measurements of Slope of Convenient Asset Demand Curve



Note: Recreates deficit-debt diagram implied by the Mian et al. (2022) model, with different assumptions for the slope of the convenient asset demand curve. Other model calibrations are identical to those in Mian et al. (2022), and reflect the US macroeconomic state in late 2019. Sources: Author's calculations, D'Avernas and Vandeweyer (2022), Greenwood et al. (2015b), and Mian et al. (2022).

This curve shows combinations of deficit and debt that support a steady-state. It can also be used to understand transition dynamics away from a steady state. Suppose an economy at steady state A increases deficits, immediately and permanently, from $\tilde{z}_1$ to $\tilde{z}_2$. Because debt, deficit pairs *above* the locus (i.e. deficits that are larger than those for which debt is constant) correspond to increasing levels of $\tilde{b}$, this suggests that $\tilde{b}$ will increase until contacting the locus again, at a higher level of debt $\tilde{b}_2$.

The deficit-debt diagram in this model can show the *maximum* sustainable quantity of government debt, and the deficit that supports it. These are the highest levels of $\tilde{z}$ and $\tilde{b}$ on the locus – $\tilde{b}^*$ and $\tilde{z}^*$. In the baseline parameters assumed by Mian et al. (2022), these occur at a deficit equal to 2% of GDP, and government debt level equal to 109% of GDP.

Mian et al. (2022) is open about how important the assumed slope of the convenient asset demand curve is for these conclusions. Flatter convenient asset demand means that a given level of government debt $\tilde{b}$ is associated with a *larger* primary deficit $\tilde{z}$, via smaller interest expenses $R\tilde{b}$. The figure in the left panel of Figure 14 assumes $\tilde{b}\frac{\partial(\rho+G-R)}{\partial\tilde{b}} = -1.7\%$.

With a series of arithmetic calculations described in Appendix E of their paper, Mian et al. (2022) note that the estimates of Greenwood et al. (2015b) suggest a value of -1.4%. Performing the same arithmetic transformation for the estimates in the published version of D'Avernas and Vandeweyer (2022) yields an estimate of -0.78%. The implied deficit-debt diagrams are shown in the right panel of Figure 14.

The same transformation for the estimates suggested by my results suggest a value of -0.3%. The value corresponding to the 90% confidence interval *lower-bond* for my stock effect is -0.5%.[38].

The flatter demand curves suggested by my estimates have very large implications for the quantitative conclusions of this simple model – suggested by the visual differences in the deficit-debt diagrams. The values of Greenwood et al. (2015a) suggest a maximum debt, deficit combination of 114% and 2.03% of GDP, respectively. The flatter demand curve estimates of D'Avernas and Vandeweyer (2022) correspond to a maximum debt, deficit of 177% and 2.4% of nominal GDP, respectively. My point estimates of the convenience yield effect of T-bill supply shocks suggest a pair of 345% and 4.0% of GDP for debt and deficit. The largest convenience yield responses not rejected by my estimates at the 90% level suggest 240% and 3% of GDP.

In discussing this calibration exercise, I do not suggest that these values should be taken as conclusive measurements of fiscal sustainability. This is a simple, stylized model that omits many realistic qualities of the fiscal sustainability problem, like private capital and aggregate – many of which are discussed in later sections of Mian et al. (2022). It surely does not suggest any normative conclusions that these levels

[38]This is the lower-bound suggested by the power-preserving GMM estimation of Section 7.5

of debt and deficit are *optimal*.

That said, this exercise shows how steepness in the convenient asset demand curve acts as much *less of a constraint* on the sustainability of different deficit, debt combination, given my estimates. This mechanism will still feature in richer, more realistic models. My estimates suggest that this steepness alone does not appear to the general fiscal policy implication of Blanchard (2019), that $R < G$ makes many combinations of debt and deficits appear sustainable.

10 Conclusion

In this paper, I have introduced a new short-term instrument for convenient asset supply. This instrument is based on T-bill issuance surprises, relative to the projections of Wrightson's Money Market Observer, a prominent money market newsletter. These surprises avoid concerns about opportunistic issuance by the Treasury, which might otherwise identification. Unlike the literature's previous approach, Wrightson surprises are more robust to the possibility of seasonality in convenient asset *demand*

With this new instrument and a local projection approach that differs from preceding empirical frameworks in this literature, I show that short-run effects of T-bill supply surprises are substantially larger than long-run effects. Imposing a simple, structural restriction that the T-bill convenience yield depends on the then-current *stock* and *flow* of T-bill supplies, I use my estimated impulse response to estimate these two effects separately. The estimates suggest that a \$100 billion increase in the supply of T-bills depresses convenience yields by 10.4bps – a much larger effect than previous studies have reported. However, this large effect is short-lived, leading to a point estimate of the stock (i.e. long-run) effect of only 1.1 basis points. This stock effect is not statistically significant under my baseline GMM approach. It is statistically significant, and somewhat larger, under an alternate power preserving GMM approach that uses *updates* in Wrightson's projections of future T-bill supply in surprise weeks as additional instruments for future T-bill supply. This alternate approach features a more restrictive exclusion restriction, but retains valuable variation about which surprises are expected to produce transitory or persistent changes in future supply.

My estimates, which suggest a steeper short-run convenient asset demand curve but a *flatter* long-run demand curve, will tend to suggest more fiscal sustainability in models where $R < G$. I demonstrate this by repeating a simple but powerful calibration exercise from Mian et al. (2022), based on US data as of the end of 2019. My estimates, used in their simplest framework, suggest that larger long-run deficits can still support a steady state with constant fractions of debt to GDP.

A Seasonality Instruments

The most common practice for estimating β in this literature is using a single equation method, either via OLS or via 2SLS with seasonality instruments. First, I show that single equation methods likely mask substantial *horizon* heterogeneity in the convenience yield response to supply changes. Even simple OLS results suggest that the short-run response to a supply change is substantially larger than the medium-run response. Next, I show that the seasonality instruments of Greenwood et al. (2015b), which provided sensible results in a pre-crisis sample, do not have the theoretically-suggested effect on β estimates in a post-crisis sample, compared to the simple OLS estimation.

A.1 Misspecification in Single Equation Estimates

A single equation, seasonal instrumental variables approach over the pre-crisis sample shows large effects of T-bill supply movements on convenience yields, but little effect in the post-crisis era. In both the pre-crisis and post-crisis sample, there is evidence that a single equation estimated in 4-week differences masks information about the horizons over which these effects matter.

The most common specification in the literature for using high frequency data to estimate β involves an estimating, via OLS or instrumental variables, a four-week differenced variant of the long-run convenient asset demand curve, Equation (1) above. That is, most researchers begin with the equation[39]

$$\frac{i_t - i_t^B}{1 + i_t} - \frac{i_{t-4} - i_{t-4}^B}{1 + i_{t-4}} = \alpha + \beta \left(B_t - B_{t-4} \right) + \xi_t - \xi_{t-4} \tag{18}$$

Of course, this specification will be inconsistent with my structural framework above in the event that $B_t - B_{t-4} \neq B_t^* - B_{t-4}^*$ (as is the case in my model of sluggish adjustment). From Equation (**??**) above we can see that under my model, even in the case where B_t and ξ are uncorrelated, the estimate $\hat{\beta}$ in this equation will be a consistent estimator only of a complicated function of β, ϕ, μ, and the population autocorrelation of B_t. This specification also implies a permanence of the effect captured in $\hat{\beta}$. This equation suggests that the convenience yield response will only tend to reverse if convenient asset supplies themselves reverse.

OLS estimates in Table 1 below offer initial suggestive evidence, from two non-overlapping subsamples, that estimates of $\hat{\beta}$ from these single equation specifications are driven primarily by a very strong effect at the shortest horizons. I show this by first estimating Equation by OLS, in pre-crisis and post-crisis samples in columns 1-2. I then estimate two variants of Equation (18) by OLS: One in columns 3-4

[39] #Note to self: Check that this is true for the non-GHS, recent papers, or if the specification is slightly different

mimicking the specification with one-week differences, and another in columns 5-6 conducting a horse race between $B_t - B_{t-1}$ and $B_{t-1} - B_{t-4}$.

	Δ4.OIS-Bill, 4w	Δ4.OIS-Bill, 4w	Δ4.OIS-Bill, 4w	Δ4.OIS-Bill, 4w
Δ4.All Bills /GDP	-2.18^{***}		-12.14^{***}	
	0.68		4.59	
Δ.All Bills /GDP		-13.62^{***}		-51.94^{***}
		1.69		8.76
L.Δ3.All Bills /GDP		1.14		−0.39
		0.90		4.89
R^2	0.02	0.09	0.03	0.11
N	575	575	311	311
Sample	2009 − 2019	2009 − 2019	2002 − 2008	2002 − 2008
Estimation	*OLS*	OLS	OLS	OLS

Table 5: Single Equation OLS Estimates

The results suggest that forcing ΔB_t and $B_{t-1} - B_{t-4}$ to share the same parameter estimate in this setting is a misspecification. Instead, it appears that the entirety of the single equation, four-week difference coefficient estimate is driven by a very strong, very short-lived effect. This finding is shared in both the pre-crisis and post-crisis samples.

A.2 Seasonal Instrumental Variables

Instrumenting for seasonal supply in regressions of this form will produce inconsistent estimates if there is a seasonal component to convenient asset demand that is correlated with the seasonality in T-bill supply. Single equation IV results estimated over the post-crisis period are consistent with a positive correlation between these seasonalities, which would tend to attenuate estimates of β.

A standard estimating approach in the literature is to instrument for T-bill supply using seasonality, in the single equation approach. This practice comes from a simultaneity concern that I will refer to in this paper as *opportunistic issuance*.[40] If the US Treasury tends to respond to positive convenience demand shocks (which raise the convenience yield) by issuing more T-bills, then that will induce a positive correlation between B_t and the unobserved structural residual in this case, $\xi_t - \xi_{t-4}$. Estimating $\hat{\beta}$ using the seasonal variation in $B_t - B_{t-4}$ alone is meant to combat this worry, because the seasonality in T-bill supply comes from a well-understood source – the timing of concentrated fiscal cash receipts around predictable calendar dates. The Treasury's typical practice of decreasing T-bill supplies after April 15th,

[40] An equivalent way of phrasing this worry is that the US Treasury's T-bill *supply* curve may be upward-sloping in the convenience yield.

for instance, is almost certainly a result of the influx of federal cash on tax day and not a response to demand conditions. In practice, this seasonal IV approach is typically implemented by using 52 week of year dummy variables as instruments when estimating Equation 3.

While a seasonal IV approach addresses worries about opportunistic issuance, it does not address other concerns of omitted variable bias that threaten to violate the exclusion restriction. For seasonality to serve as a valid instrument in this setting, it must be true that seasonal variation in T-bill supply is uncorrelated with changes in demand conditions. Violations of this exclusion restriction need not be causal. To threaten the exclusion restriction, it need only be true that there exists some seasonality in convenient asset demand that is correlated with the seasonality in T-bill supplies.

There is ample reason to believe that there exists a seasonal component in T-bill demand, especially in the post-crisis sample of this paper. Firms preparing for cash outflows related to payroll or year-end bonuses may desire a T-bill's perfect nominal safety or convenience more in the run-up to those payments. Regulated financial institutions that value convenient assets holdings for regulatory reasons may desire those holdings more strongly before a month-end of quarter-end regulatory filing. Or, financial institutions attempting to window dress their leverage ratios at quarter-end or month-end may limit their issuance of private sector substitutes for T-bills at those times.[41]

In the post-crisis sample of this paper, the way in which the seasonal IV affects estimates of $\hat{\beta}$ is no longer consistent with the assumption that justified their use, that seasonal variation is less positively correlated with demand than nonseasonal variation. In column 1 of Table 2, we estimate β by regressing one-week differences in the convenience yield on one-week changes in T-bill supplies, on a post-crisis weekly sample from 2009-2019. The results are negative and significant, and indicate that a one-week increase in T-bill supplies equal to 1% of nominal GDP decreases the T-bill convenience yield by 2.84 basis points. In column 2, we estimate the same equation by 2SLS, using 52 week-of-year dummy variables as instruments for ΔB_t. Unlike in Greenwood et al. (2015b), which is estimated on a pre-crisis sample, this procedure *attenuates* the observed effect and causes it to lose statistical significance. In column 3, I take the opposite approach to column 2 by controlling for 52 week-of-year dummy variables. Column 2 relies on sesaonal variation for identification, while column 3 removes seasonal variation in T-bill supplies in identification. In the opportunistic issuance story that justifies the seasonality instrument, seasonal variation in supplies is the variation that should create a larger magnitude effect on convenience yields. The results of Table 2 instead suggest the opposite - that sesaonal variation in T-bill supplies has a weaker connection to convenience yields. These results are consistent with the interpretation that, in a post-crisis sample, seasonality in T-bill supplies is positively correlated with seasonality in unobserved

[41] Window dressing of this sort has been convincingly documented in Du et al. (2018).

convenience demand shifters.[42]

These results suggest that a new approach is needed for estimating β using post-crisis data.

	(1)	(2)	(3)
	Δ.OIS-Bill, 4w	Δ.OIS-Bill, 4w	Δ.OIS-Bill, 4w
Δ.All Bills /GDP	-2.84^{**}	-0.45	-4.54^{***}
	1.14	1.86	1.55
R^2	0.01	0.00	0.18
N	575	575	575
Sample	$2009-2019$	$2009-2019$	$2009-2019$
Estimation	OLS	Seasonal IV	Seasonal Controls

Table 6: Seasonal Instrumental Variables

[42]Of course, it is also consistent with a story that non-seasonal variation in T-bill supply is *negatively* correlated with unobserved demand. Differentiating between these two stories is challenging, of course.

A.3 Structural Estimates of ξ and Seasonality

B GMM Estimates with 2-Parameter Investor Inertia

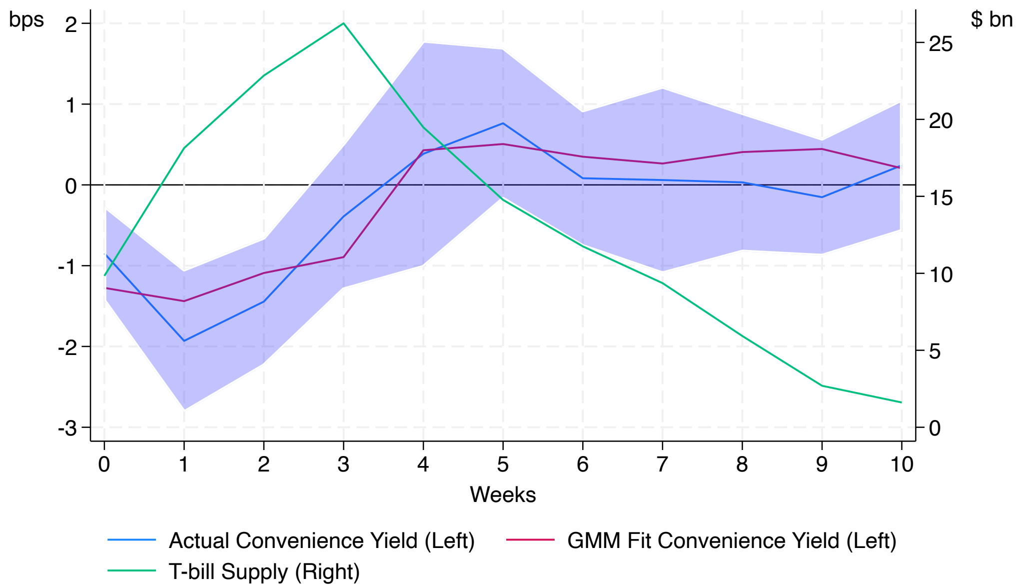


Figure 15: GMM Fit with Two-Parameter Investor Inertia Model

Note:

C Wrightson Treasury Coupon Surprises

D Additional Information on Treasury Issuance Policy

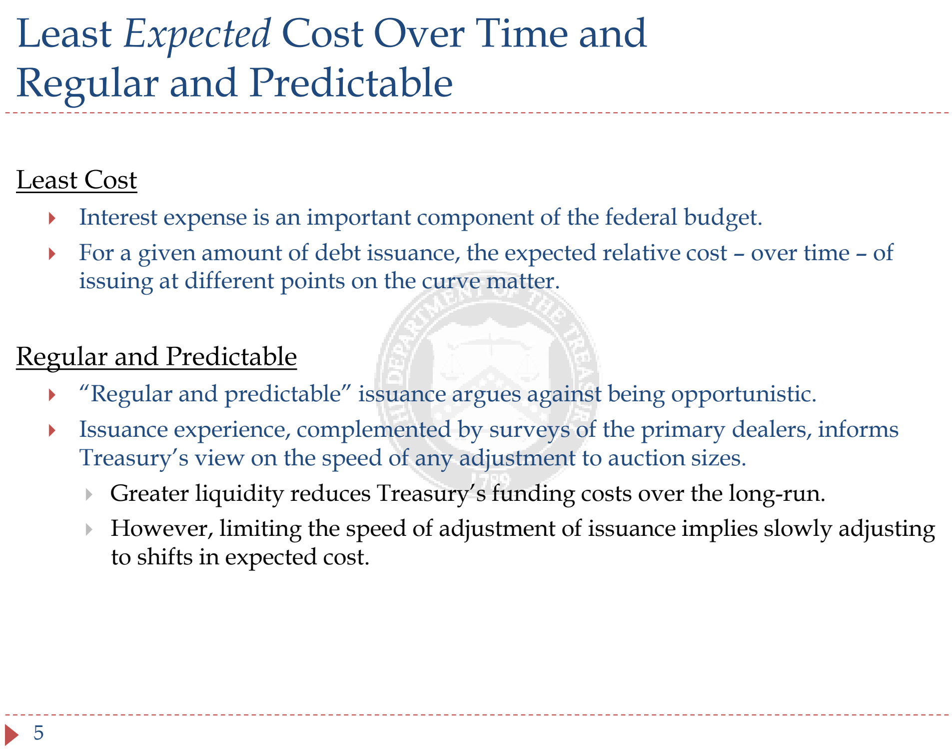


Figure 16: Additional Informative Slide from Treasury Presentation

Note:

E GMM Estimates with Pre-Specified Weight Matrix

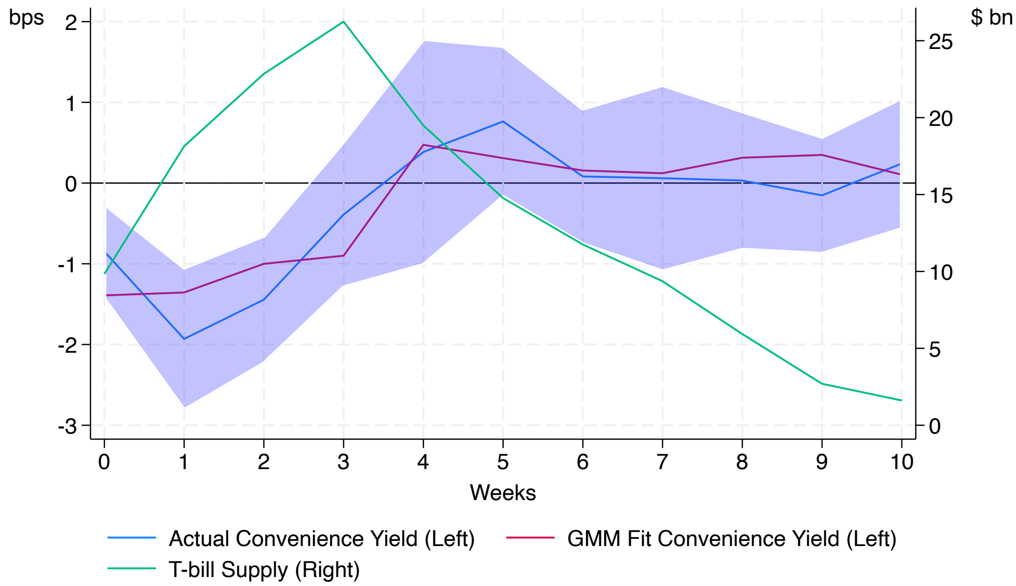


Figure 17: GMM Fit with Pre-specified GMM Weight Matrix, Identity

Note:

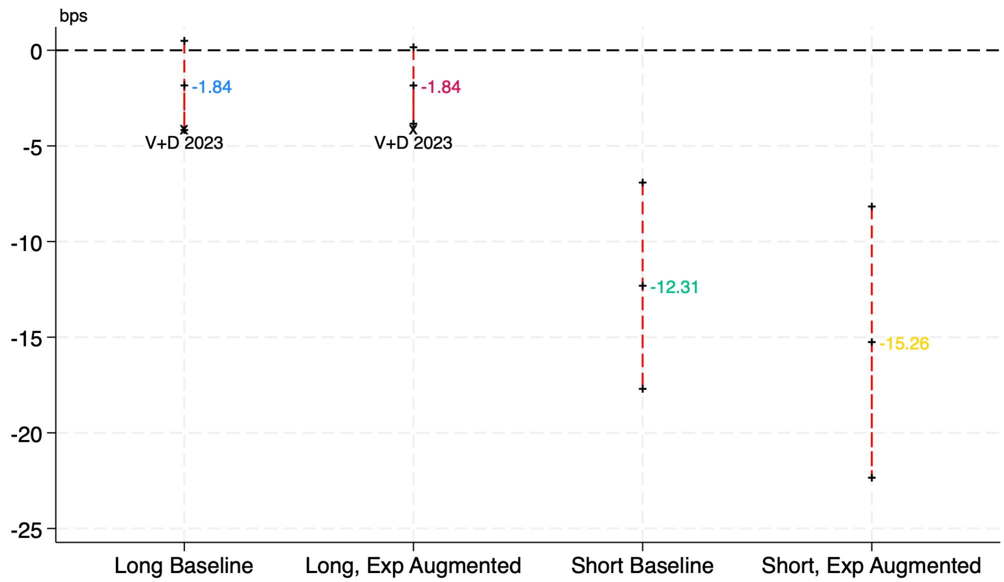


Figure 18: GMM Stock and Flow Estimates with Pre-specified GMM Weight Matrix, Identity

F Cyclicality of Fiscal Surprises

A channel through which our exclusion restriction could be violated is if changes in convenient asset demand are correlated with revisions to market expectations of future receipts or expenditures. That is, an alternate set of conditions that will tend to violate the exclusion restriction is

$$\mathbb{C}(\mathbb{E}_{t,Priv}(e_{t+k}) - \mathbb{E}_{t-\delta,Priv}(e_{t+k}), \varepsilon^D_{t+h}) \neq 0$$
$$\mathbb{C}(\mathbb{E}_{t,Priv}(e_{t+k}) - \mathbb{E}_{t-\delta,Priv}(e_{t+k}), B_t - \mathbb{E}_{t-\delta,Priv}B_t) \neq 0$$

and analagously for receipts r_{t+h}. The second of these is almost surely true: A surprise in T-bill issuance will almost certainly cause private actors to update their expectations of future receipts or expenditures.

My first evidence in favor of the exclusion restriction is that federal government receipt and expenditure surprises at high frequencies have very little power in predicting other macroeconomic variables that could plausibly drive the cyclicality in convenience demand. I demonstrate this using a sensible proxy for well-informed agents' expectations of government receipts, government expenditures, and other macroeconomic variables. As my proxy, I use pre-FOMC projections by Federal Reserve Board economists from the Federal Reserve Tealbooks. Using this data, I wish to show whether quarterly surprises (relative to the Tealbook projections) in government expenditures or receipts tend to be correlated with quarterly surprises in other macroeconomic variables of interest.

To show this, I estimate a simple set of OLS regressions meant to transparently show whether this correlation exists, and at what frequencies of surprise it tends to be most severe. Specifically, I estimate OLS regressions of the form

$$Z_t - \mathbb{E}_{t-h,FOMC}(Z_t) = \alpha + \gamma(G_t - \mathbb{E}_{t-h,FOMC}(G_t)) + e_t$$

where $G \in \{\text{Receipts}, \text{Expenditures}\}$, and Z is some other macroeconomic object of interest as indicated. The object $\mathbb{E}_{t-h,FOMC}$ represents the Tealbook projections for some variable's realization in quarter t, as of the first available projection in quarter $t-h$. That is, $\mathbb{E}_{t,FOMC}(X_t)$ indicates a start-of-quarter projection of a quarterly realization that will not be known until the end of the quarter and so, in general, $X_t \neq \mathbb{E}_{t,FOMC}(X_t)$.

Consistent with the sensible intuition that fiscal flows have a cyclical component, there is evidence that receipt and expenditures surprises are tied to business cycle innovations at horizons around 1-year. Evidence to this effect is show in Table 7, which shows results from estimation equation 4 vis OLS, with $Z \in \{\text{Nominal GDP Growth}, \text{Real GDP Growth}\}$ and $h \in \{0, 1, 2, 3, 4\}$. The most striking components of this table are the R^2 measures. At the 1-year horizon, government receipt and expenditure surprises have a moderately predictive quality for real and nominal GDP growth surprises. The peak is for tax receipt surprises, which help explain 10% and 5% of nominal and real GDP growth surprises, respectively. Although note that, even at this horizon, the R^2 for tax receipts is notably less than that for any of the other righthand side macroeconomic variable shown.

This evidence disappears at shorter horizons, so that same-quarter receipt and expenditure projection errors appear wholly disconnected from other macroeconomic surprises. The bottom panel of Table 7 shows this most clearly, where the R^2 measure for same-quarter receipt and expenditure surprises predicting same-quarter GDP growth surprises has fallen nearly to zero. The progression from the top $h = 4$ panel to the bottom $h = 0$ panel shows the steady decline, both in the R^2 measure and the statistical significance of the regression coefficients, as we study surprises at higher and higher frequencies.

The most relevant panel in Table 7 for considering the plausibility of this paper's exclusion restriction is the bottom panel, studying same-quarter surprises. This is for two reasons. First, my proxy for T-bill issuance surprises will be based on a private actor's projections as of just hours before the associated announcement. As such, any information known by private actors at any longer frequencies should already be incorporated into the private expectations. Second, I will show below that, while high frequency T-bill surprises should indeed shift private agents' expectations of future receipts and expenditures, they only do so are relatively short horizons of the following several weeks. The conclusion to draw from these facts is that the receipt and expenditure information content of T-bill issuance surprises in this paper share the most in common with the highest-frequency surprises shown in Table 7.[43]

[43]# Note to preliminary reader: I am open to suggestions about how to alter this table to better fit onto a single page. Shrinking fonts beyond their current level seems like a bad idea. But I do like display all of the $h \in \{0, 1, 2, 3, 4\}$ results, so readers can see the progression of coefficients and R^2.

$h=4$	NGDP	NGDP	NGDP	NGDP	NGDP	RGDP	RGDP	RGDP	RGDP	RGDP
Housing Starts	5.78^{***}					5.64^{***}				
	1.2					1.1				
Unemployment		-1.31^{***}					-0.90^{**}			
		0.4					0.4			
Receipts			2.43^{***}					1.56^{**}		
			0.6					0.6		
Outlays				-0.17^{***}					-0.07^{***}	
				0.0					0.0	
Outlays - OMF					-0.18^{***}					-0.07^{***}
					0.0					0.0
N	144	144	140	140	140	144	144	140	140	140
R^2	0.20	0.14	0.10	0.08	0.08	0.22	0.08	0.05	0.01	0.01

$h=3$	NGDP	NGDP	NGDP	NGDP	NGDP	RGDP	RGDP	RGDP	RGDP	RGDP
Housing Starts	7.02^{***}					6.39^{***}				
	1.4					1.3				
Unemployment		-1.83^{***}					-1.31^{***}			
		0.4					0.4			
Receipts			2.28^{***}					1.38^{**}		
			0.7					0.7		
Outlays				-2.21^{**}					-1.86^{*}	
				1.1					1.0	
Outlays - OMF					-1.92^{**}					-1.58^{**}
					0.9					0.8
N	157	157	151	151	151	157	157	151	151	151
R^2	0.18	0.16	0.06	0.05	0.06	0.20	0.11	0.03	0.04	0.05

$h=2$	NGDP	NGDP	NGDP	NGDP	NGDP	RGDP	RGDP	RGDP	RGDP	RGDP
Housing Starts	8.80^{***}					7.99^{***}				
	1.5					1.4				
Unemployment		-2.61^{***}					-1.98^{***}			
		0.5					0.4			
Receipts			2.01^{**}					1.12		
			0.8					0.8		
Outlays				-1.29					-1.22	
				1.0					0.9	
Outlays - OMF					-1.48^{*}					-1.32^{**}
					0.8					0.7
N	159	159	152	152	152	159	159	152	152	152
R^2	0.23	0.22	0.04	0.02	0.04	0.24	0.16	0.01	0.02	0.04

$h=1$	NGDP	NGDP	NGDP	NGDP	NGDP	RGDP	RGDP	RGDP	RGDP	RGDP
Housing Starts	9.17^{***}					8.79^{***}				
	1.3					1.3				
Unemployment		-3.41^{***}					-2.67^{***}			
		0.5					0.5			
Receipts			1.09					0.49		
			1.0					0.9		
Outlays				-0.60					-0.79	
				1.2					0.9	
Outlays - OMF					-0.81					-0.80
					0.8					0.7
N	159	159	152	152	152	159	159	152	152	152
R^2	0.24	0.23	0.01	0.00	0.02	0.25	0.16	0.00	0.01	0.02

$h=0$	NGDP	NGDP	NGDP	NGDP	NGDP	RGDP	RGDP	RGDP	RGDP	RGDP
Housing Starts	9.05^{***}					8.47^{***}				
	2.4					2.1				
Unemployment		-4.82^{***}					-3.88^{***}			
		1.0					0.9			
Receipts			0.42					-0.29		
			1.4					1.3		
Outlays				0.95					1.07	
				0.8					0.7	
Outlays - OMF					0.46					0.49
					1.0					1.0
N	159	159	152	152	152	159	159	152	152	152
R^2	0.14	0.22	0.00	0.01	0.00	0.15	0.17	0.00	0.01	0.00

Table 7: Greenbook Fiscal Surprise Regressions

There is some evidence that same-quarter tax receipt surprises today can help predict GDP growth surprises in the following quarter, but there is no evidence for the same from expenditures. To reach this conclusion, we estimate a similar set of equations via OLS, with instead

$$Z_{t+1} - \mathbb{E}_{t,FOMC}(Z_{t+1}) = \alpha_2 + \gamma_2(G_t - \mathbb{E}_{t,FOMC}(G_t)) + w_t$$

This specification instead asks whether a same-quarter receipt or expenditure surprises this quarter should shift the Tealbook forecasters' projections for GDP growth in the following quarter. While R^2 values are quite modest, and below those of more-closely watched macroeconomic indicators such as housing starts and industrial production, there is some evidence that tax receipt surprises are informative for the following quarter's nominal GDP projections (although not real GDP growth projections). However, we see no such result for government outlays.

$h = 1QForward$	NGDP	NGDP	NGDP	NGDP	NGDP	NGDP	RGDP	RGDP	RGDP	RGDP	RGDP	RGDP
Receipts	3.74***		3.54**		3.52**		1.99		1.87		1.80	
	1.4		1.5		1.4		1.4		1.4		1.4	
Outlays		1.19	0.70					0.70	0.44			
		1.0	1.0					1.1	1.1			
Outlays - OMF				1.43*	1.24*					1.23*	1.13	
				0.7	0.7					0.7	0.7	
$fund_need_temp$						0.24						0.52
						0.8						0.7
N	151	151	151	151	151	151	151	151	151	151	151	151
R^2	0.04	0.01	0.04	0.02	0.05	0.00	0.01	0.00	0.01	0.02	0.03	0.00

Table 8: Fiscal Surprises, Forward Looking

Taking these analyses as evidence that any links between convenient asset demand and the fiscal information content of T-bill surprises is likely to be low, I proceed next to introducing my measure of T-bill surprises and presenting my principal results. Further exploring the likely quantitative implications of the final result of this section, that tax receipts but not expenditures may be informative of next quarter's future GDP growth, is the subject of Section G of this paper. In very brief summary, restricting my shock measure to only those T-bill surprises likely to be least informative about future tax receipts has nearly no effect on any of the quantitative results of this paper.

G Treasury Information Effects

The quarterly analysis of fiscal surprises in Section **??** left open the possibility of a moderate capacity for same-quarter surprises in government receipts to predict next quarter's macroeconomic fundamentals. I show that any added macroeconomic informativeness of Wrightson T-bill issuance surprises is unlikely to drive any sizable share of my convenience yield impulse response results. I do this by separately estimating impulse responses for T-bill surprises that are *more* and *less* informative about future government tax receipts, and show that the two impulse responses are quantitatively very similar.

G.1 Intuition

The empirical test to follow will assess whether Wrightson issuance surprises that occur in weeks where T-bill issuance is especially *informative* about future tax receipts have meaningfully different impulse response estimates than surprises in tax uninformative weeks. I identify tax informative weeks as weeks in the data where relatively more variation in near-future treasury net cash flows comes from tax receipts, for seasonal reasons. This test determines whether the information content about tax receipts has a separate effect on T-bill convenience yields that differs from information content about expenditures. This is informative about the plausible *total* magnitude of tax receipt information effects because the low-frequency analysis of Section **??** suggests that the macroeconomic informativeness of high frequency government expenditure surprises is close to zero.

The quarterly analysis of section **??** suggests that the ideal experiment for studying T-bill supply shocks with zero demand-shifting information content would study T-bill issuance surprises that are unambiguously interpreted by market participants as arising from government *expenditure* surprises. Whatever modest correlation that exists between same-quarter fiscal surprises and future macroeconomic outcomes appears to be restricted to government receipts and does not extend to expenditures. Thus, a T-bill issuance surprise that market participants understand is driven by expenditures alone is most-likely to be free of any information content that would affect how investors value asset convenience.

That ideal experiment is not empirically feasible, given my data. The US Treasury does not give an accounting of the precise reasons why they issue their chosen quantities of T-bills. While Wrightson's Treasury commentaries sometimes will offer an interpretation of what might have driven a given issuance surprise, those discussions are not sufficiently common to construct a large sample of surprises widely interpreted as arising from expenditures alone. While Wrightson does now publicize their Treasury cash flow projections, they only began doing so in 2017, leaving limited overlap with my 2009-2019 sample.

However, the well-known seasonal pattern in federal government receipts (and, indeed, for many expenditures) makes it feasible to isolate a subsample of T-bill issuance surprises that are substantially *more* informative about the Treasury's private information regarding future tax receipts. Three qualities of the Treasury's T-bill issuance program allow this. First, strong seasonality in tax receipts centered around federal tax deadlines mean that a greater share of the *uncertainty* in Treasury net cash flows comes from tax receipts in the weeks surrounding these deadlines. Second, the Treasury's desire to smooth T-bill issuance sizes over time means that they will tend to respond *today* to private information about near-future cash flows. Third, because greater (or smaller) issuance of 4-Week T-bills directly affects the Treasury's cash balance only over the next four weeks, the Treasury's 4-Week T-bill issuance decision today will tend to be most informative about the Treasury's expectations of cash flows over the next four weeks.

Motivated by these qualities, I define a "tax informative" T-bill issuance surprise as a Wrightson issuance surprise occurring in a week where more of the near-term variation in Treasury cash flows likely comes from government tax receipts. I define "near-term" variation in Treasury cash flows as variation over the following four weeks. I measure which weeks have greater near-term receipt variation by studying the sample variance in cash flows for a given week, but across many years, in the sample.

Figure 19 illustrates the procedure. In the left panel of Figure 19 is an example weekly time series of Treasury net tax and net non-tax cash flows, for the year 2016. That is, it plots $(\text{Net Tax Flow})_t$ and $(\text{Net Nontax Flow})_t$ for every week t in the year. Even in a single year of data, the spikes associated with tax deadlines are readily apparent. These spikes typically fall on the 15th of the final month in each quarter.

The right panel of Figure 19 shows the criteria by which I select "tax informative" weeks in the data. For each of the 52 weeks in a year, I calculate $\mathbb{V}(\sum_{\ell=0}^{4}(\text{Net Tax Flow})_{w+\ell}))$ and $\mathbb{V}(\sum_{\ell=0}^{4}(\text{Net Non-Tax Flow})_{w+\ell}))$ in each week w, where $\mathbb{V}$ signifies a sample variance of each week w in my sample (i.e. variance within week w's, but across *years* in the data). These sample variances of forward-looking cumulative cash flows are my proxy for near-future cash flow *uncertainty* coming from the two fundamental components of cash flows: receipts and expenditures. The object plotted at each week w in the right panel of Figure 19 is $\frac{\mathbb{V}(\sum_{\ell=0}^{4}(\text{Net Tax Flow})_{w+\ell})}{\mathbb{V}(\sum_{\ell=0}^{4}(\text{Net Non-Tax Flow})_{w+\ell})}$, the ratio of tax and non-tax variance.

A week is selected as a "tax informative" week if this ratio is greater than the median ratio across all 52 weeks. In both the left and right panels, red dots signify the weeks of the year that are selected as "tax informative" by this metric. The left panel lends the intuition – tax informative weeks are typically the four weeks preceding (and sometimes a single week after) each of the five major spikes in tax receipts. The fact that the selection criteria, which is based off an empirical moment *across* years in the data, selects weeks in this particular year that sensibly correspond to these spikes is an indicator that this tax deadline seasonality is roughly calendar-constant across years in the sample.

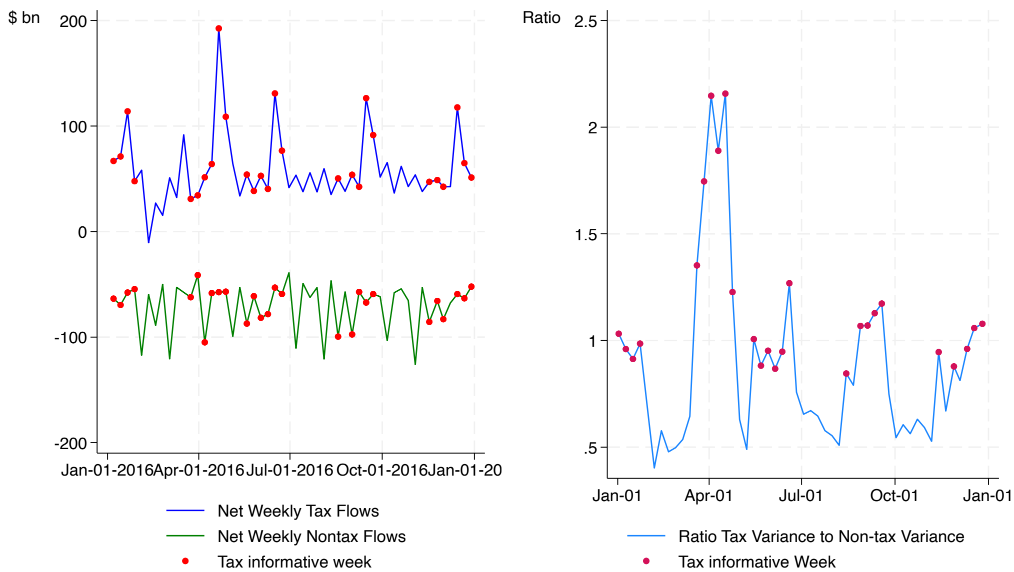


Figure 19: Tax Informative Weeks

G.2 An Illustrative Model

I construct a simple but realistic Treasury T-bill issuance model, in which the Treasury partially reveals its private information about future cash flows via its public T-bill issuance decisions. I use to model to show that a rational private agent should indeed view T-bill issuance decisions in the weeks before a seasonal tax deadline as more informative about the Treasury's private receipt information.[44]

In the model, the Treasury balances two objectives: to keep its cash balances close to some target level, and to avoid changing T-bill issuance sizes too quickly. The first is consistent with the Treasury's tendency to discuss "target" cash balances for particular dates. The second is consistent with the Treasury's stated objective to keep issuance "regular and predictable". We represent these with the objective function

[44]#Note to preliminary reader: This paragraph used to have another sentence in it, to reflect a result that I couldn't get ready in time for this draft. It was meant to read: "Via a simulated time series, I show that estimated convenience yield impulse responses from surprises in high and low tax informative weeks should exhibit different impulse responses, if tax receipt information does indeed move convenience yields in an economically meaningful way."

$$\min_{B_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(c_t^2 + \gamma_1 (B_t - B_{t-1})^2\right) \tag{19}$$

$$c_t = c_{t-1} + B_t - B_{t-4} + r_t - e_t - r_{t-H} + e_{t-H} \tag{20}$$

Here, c_t represents the deviation of the Treasury's cash balance from some target level. B_t is T-bill issuance this week. In the model, every T-bill issued by the Treasury has a 4-week maturity. As such, B_{t-4} represents the T-bills *maturing* this week, which must be redeemed for investors and thus contribute negatively to this week's cash flows. r_t are today's cash receipts, which contribute positively to the cash balance. e_t are today's expenditure, which contribute negatively.

The objects r_{t-H} and e_{t-H} represent a tendency by the Treasury to eventually finance government surpluses using issuance of unmodeled, longer-term coupon *bond* issuance. In the model, this means that a \$1 net cash flow today will affect T-bill issuances in the near-term, but not the long-term. While a simplifying abstraction, these objects ensure that this model embodies the Treasury's short-term *cash management* problem, which is likely most important at the high frequencies of this paper. The longer-term Treasury *debt management* problem remains unmodeled.

I model the law of motion of the fiscal objects r_t and e_t as

$$r_t = \phi_{w(t)} y_t \tag{21}$$

$$y_t = \rho_y y_{t-1} + \varepsilon_t^y \tag{22}$$

$$e_t = \varepsilon_t^e \tag{23}$$

$$\varepsilon_t^y \sim N(0, \sigma_y^2) \tag{24}$$

$$\varepsilon_t^e \sim N(0, \sigma_e^2) \tag{25}$$

$$0 = \mathbb{C}(\varepsilon_t^y, \varepsilon_e^e) \tag{26}$$

Receipts in the model are a simple linear function of the persistent state variable y_t, which is observable to the Treasury but will be unobservable to private market participants. I will consider the possibility that the state variable y_t is some macroeconomic indicator that is relevant for investors' demand for safe, convenient assets. However, the loading $\phi_{w(t)}$ which maps the macroeconomic state y_t into receipts r_t is *seasonal*, and will depend on the week t's placement in the quarter (i.e. $w(t) \in \{1, 2, \cdots, 13\}$). In my illustrative numerical example, I will have $\phi_i = 0$ for $i \in \{1, 2, \cdots, 12\}$ and $\phi_{13} >> 0$. That is, all of the quarter's tax receipts arrive in the cash account in the last week of each quarter.

Private agents in the model have an informational disadvantage compared to the Treasury. For private agents, the observable state variables in the model include c_{t-1}; the history of past receipts $r_{t-\ell}\ \forall \ell \geq 1$; the history of past expenditures $e_{t-\ell}\ \forall \ell \geq 1$; current T-bill issuance B_t; and all past T-bill issuances $B_{t-\ell}\ \forall \ell \geq 1$.

However, the private agents *cannot* observe the state variable y_t, current receipts r_t or current expenditures e_t.

The private agents in the model know the parameters of the Treasury's objective function, meaning that they know the mapping between state variables (both observable and unobservable) and the Treasury's choice variable B_t. Because the Treasury's problem has the well-known, linear quadratic setup, the Treasury's T-bill issuance policy function is a linear function of the state variables observable to the Treasury. As such, the information structure of the model admits a linear state space representation with Gaussian shocks.

Like other linear state space models with normally distributed shocks, private agents' *updates* to their expected values of each state variable can be solved for iteratively via the Kalman filter. A departure of this setup from the simplest, canonical Kalman filter application is that uncertainty in the model is *seasonal*, driven by the seasonal loading of receipts on the unknown (to private agents) state variable y_t. In this setting, the Kalman gain that maps surprises in observables into updated beliefs about next-period's state variables are season (i.e. week-of-quarter) specific.

For any choice of the four model parameters Γ_0, ρ_y, σ_e^2, and σ_y^2 it is straightforward to solve numerically for the Kalman gain matrix for each week of the quarter. At an illustrative choice of model parameters listed in the Appendix, I solve for this Kalman gain for each of the 13 weeks in a quarter. The top panel of Figure 20 shows $\frac{d\mathbb{E}_t(y_t)}{d(B_t - \mathbb{E}_{t-1}B_t)}$ – that is, how the rational private agent of the model will update their beliefs about the persistent, unobserved, underlying macroeconomic state variable y_t in response to a surprise in T-bill issuance.

The pattern of macroeconomic informativeness of T-bill issuance surprises from the model follows essentially the same pattern as my empirical implementation of the "tax informativeness" classifications. That is – the private rational agent will tend to view T-bill issuance surprises in the last four weeks before each major tax receipt inflow date (week 13 of the quarter, in the model) as particularly informative about future receipts, and thus macroeconomic fundamentals.

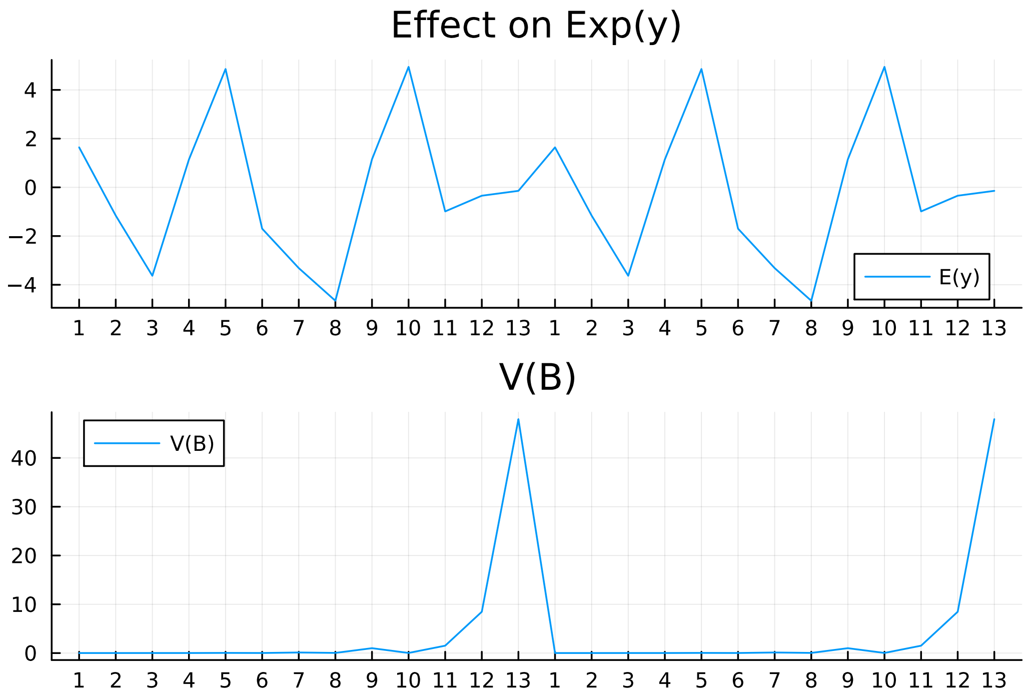


Figure 20: Seasonal Kalman Gain and T-bill Issuance Uncertainty from Model

We can also use the illustrative model to understand the implications of a hypothetical correlation between expected macroeconomic fundamentals and convenient asset demand. Recalling our notation from Section 3 that ξ_t represents factors *shifting* the convenient asset demand curve, we say that

$$\xi_t = \xi_t^e + \omega \mathbb{E}_t(y_t) \tag{27}$$

$$\mathbb{C}(\xi_t^e, \mathbb{E}_t(y_t)) = 0 \tag{28}$$

That is, we consider the possibility that $\mathbb{C}(B_t - \mathbb{E}_{t-1}B_t, \xi_t) \neq 0$, via the mechanism that T-bill issuance surprises shift private agent understandings of macroeconomic fundamentals in a way that is relevant for demand.

G.3 Empirical Test Results

The reduced form impulse response function estimates show that T-bill issuance surprises in "tax informative" periods have substantially more predictive power for future tax receipts than surprises outside the "tax informative" weeks, consistent with my story. The estimated impulse response function for T-bill convenience yields to shocks in the two periods look exceedingly similar. This is inconsistent with large tax receipt information effects driving a quantitatively meaningful share of my results.

To find suggestive evidence for this test's underlying hypothesis that T-bill issuance surprises in "tax informative" weeks have more predictive value for future Treasury net tax flows, I use a local projection approach similar to that from my earlier results. Specifically, at each horizon h I estimate

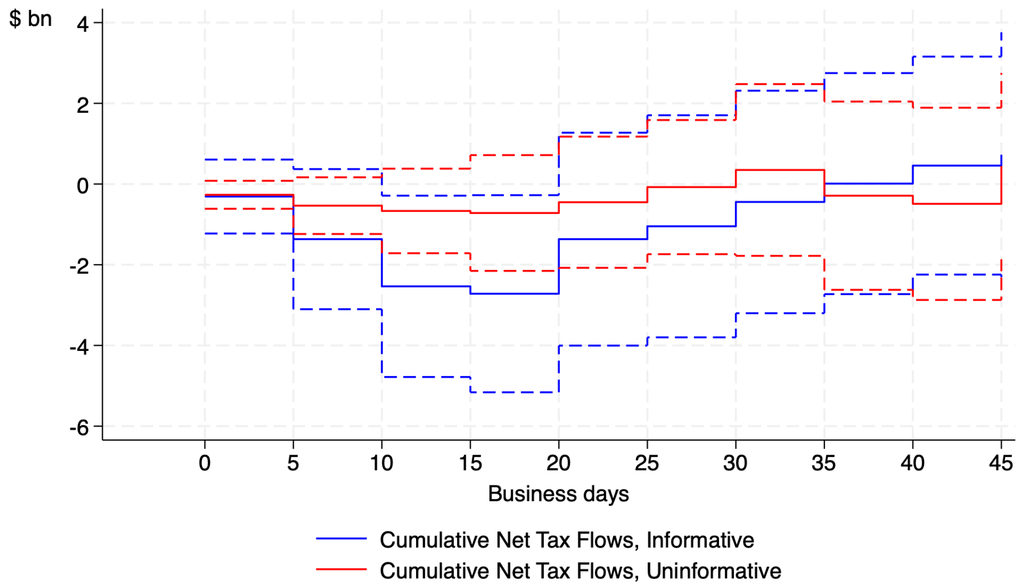
$$\begin{aligned}\sum_{\ell=0}^{h} r_{t+\ell} = \alpha_h &+ \beta_h^I \mathbf{1}\left(\text{week}(t) \in \text{Informative}\right) \times \varepsilon_t^s \\ &+ \beta_h^{NI} \mathbf{1}\left(\text{week}(t) \in \text{Not Informative}\right) \times \varepsilon_t^s \\ &+ \phi_h' X_{t-\delta} + e_{t+h} \qquad (29)\end{aligned}$$

Where r_t show net Treasury tax *flows* in week t. This means that $\sum_{\ell=0}^{h} r_{t+\ell}$ measures *cumulative* Treasury tax flows between week t and week $t+h$. In the results to come, I plot both $\{\beta_h^I\}_{h=0}^H$ and $\{\beta_h^{NI}\}_{h=0}^H$. These estimates show how T-bill issuance surprises shift expectations of cumulative tax flows differently, depending on the seasonal informativeness of week t in which the surprise was realized.

T-bill issuance surprises delivered in one of my "tax informative" weeks do indeed predict future tax receipts much more than T-bill surprises in "tax uninformative" weeks. These results are shown in Figure 21. The estimates suggest that a \$10 billion T-bill issuance surprise in an informative week should shift expectations of cumulative tax receipts over the next three weeks by -\$2.5 billion. In contrast, a a \$10 billion T-bill issuance surprise in an uninformative week should shift expectations of cumulative tax receipts over the next three weeks by only -\$0.5 billion.[45]

[45] Admittedly, confidence intervals are sufficiently wide that I cannot reject the null hypothesis that the 3-week impulse response is equal across the two subsamples.

Figure 21: Receipt Informativeness of Issuance Surprises, Informative-vs-Uninformative Weeks



To estimate different impulse responses for T-bill convenience yields in these two tax informativeness periods, I again estimate impulse response functions that allow for separate parameter estimates for shocks realized in the two periods. To do this, I estimate an alternate version of equation 29, with the lefthand side variable replaced with future realizations of the T-bill convenience yield.

Considering that these two response are estimated with nonoverlapping subsamples of shocks, the impulse response of T-bill convenienece yields across informativeness periods looks remarkably similar. These results are shown in Figure 22, where the T-bill convenience yield response to issuance surprises in a "tax informative" week are shown in red and the response to issuance surprises in a "tax uninformative" week are shown in blue. With the possible exception of an approximately weeklong period in the 4-5 week horizon, these responses look quite similar.

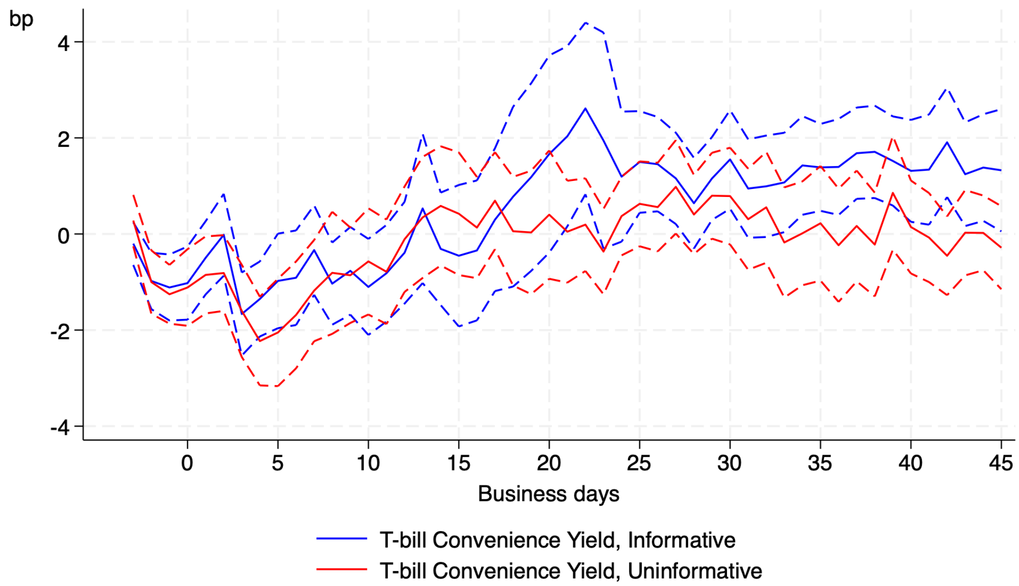


Figure 22: T-bill Convenence Yield Response By Subsample, Tax Informative-vs-Uninformative

Most importantly, these responses look *incredibly* similar at the earliest horizons, in the first few days after an issuance surprise is realized. This horizon is especially important, because the endogeneity mechanism that I am considering relies on the *information effect* of the surprise itself. If there is indeed any such meaningful information effect, we would expect to see sizable differences in the convenience yield effect near the time when that information is revealed to market participants. We surely do not see any substantial difference in convenience yield responses at these shorter horizons.

The estimates of β, ϕ, and μ^{-1} from Section 7.4 also effectively summarize the shape of the convenience yield impulse response for both of these subperiods. In Figure 22, the blue dots show the fitted convenience yield impulse response, using the estimates of β, ϕ, and μ^{-1} from Section 7.4 (i.e. the pooled sample estimates) and the estimates (not shown) of future T-bill supply to a T-bill issuance shock in a "tax informative" period. The red dots do the same, for the tax uninformative period. These dots are especially useful for understanding some differences in the impulse responses at the longer horizons of 30-45 business days, where the "informative" response lies consistently above the "uninformative" response. The dots show us that this pattern can be explained via differences in the impulse response of T-bill *supply* (quantity) at those horizons, given my estimates of β and the sluggishness parameters ϕ and μ^{-1}. The fact that the blue dots are above the red dots at those horizons reflects the fact that T-bill supplies are typically still meaningfully *falling* at those horizons after an "informative" shock, but not after an "uninformative" shock.[46]

H LP-IV Results: Future Cash Flows

On average, T-bill supply surprises today predict offsetting, non-debt net cash flows into the US Treasury's cash account in the coming weeks. This is consistent with my overall story that these surprises are driven by differences in Wrightson's and the Treasury's near-future cash flow projections.

To show that T-bill supply surprises today appear to come with 1-to-1 offsetting net Treasury cash flows in the near future, I now estimate equations (9) and (10), setting $Y_{t+h} = \sum_{\ell=0}^{h} \left(\text{Non-debt Receipts}_{t+\ell} - \text{Non-debt Outflows}_{t+\ell}\right)$. "Non-debt receipts" and "Non-debt Outflows" refer to the observable inflows and outflows into the US Treasury's General Account at the Federal Reserve. Data on inflows and outflows is publicly available, published daily at a one-day lag.

If it is indeed the case that T-bill supply surprises today are generally driven by the near-term cash needs of the federal government, then we would expect our impulse response estimates $\{\beta_{t+h}\}_{h=0}^{H}$ in this specification to be *negative*. When the Treasury surprises market participants by issuing \$10 billion more in T-bills today, that means it is raising approximately \$10 billion more today via debt issuance. If the Treasury does this to fully offset cash flows in the coming weeks, then we might expected \$10 billion more to leave the US Treasury's general account than was originally expected (i.e. negative net flows) for non-debt related reasons in the coming weeks.

Future predicted Treasury cash flows almost perfectly offset the predicted changes in near-term T-bill supply from a surprise T-bill issuance today. These results are shown in Figure 23 below. In the left panel, I plot future cumulative non-debt cash flows, along with the T-bill supply impulse response function in gray. The units on these two results are the same. The sign of near-term cumulative cash flows is negative, as expected. To facilitate comparing the magnitude of this response to the magnitude of the T-bill response, the right panel *negates* the cumulative cash flow response from the left panel. The fact that the T-bill supply response and the cumulative cash flow response lie nearly atop one another in the right panel suggests a simple, and empirically justified story of the drivers of T-bill issuance shocks: the Treasury surprises the market with increased T-bill issuance to offset future net cash flow surprises essentially one-for-one.

[46] In other words – the different convenience yield responses at those horizons can be explained by observed *supply* variation. It does not require a correlation with unobserved *demand* at those horizons.

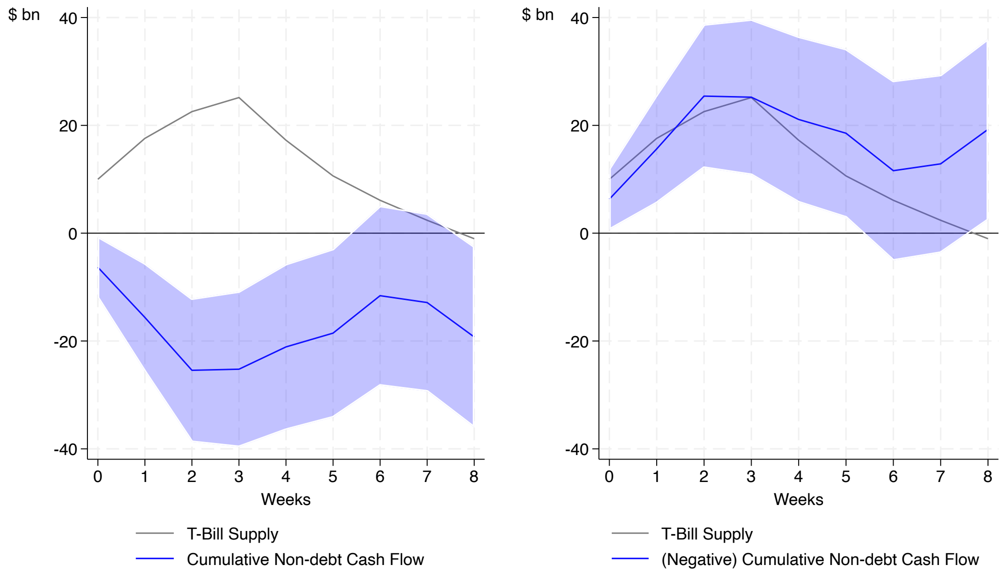


Figure 23: Impulse Response of Future Treasury Net Cash Flows

I Understanding Temporary Effects

A crucial ingredient of most limits to arbitrage models that allow for temporary effects after a supply shock is that the universe of investors who are able to absorb an increase in supply widens over time after a shock.[47] I show that holdings data from the money market mutual fund sector alone shows this quality. Treasury-only money market mutual funds appear to absorb a larger share of *surprise* 4-Week T-bill issuance in the week after a Wrightson issuance surprise, compared with surprises more than one week old.

One model with limits to arbitrage that can produce transitory price impacts after a supply shock that are smaller than the persistent component is the slow moving capital model of Duffie (2010). In that model, a sector of fast-moving investors rebalances their portfolio each period, while additional cohorts of slower-moving investors rebalance only periodically. There, an increase in the supply of some security is absorbed disproportionately by the fast investor sector in the initial periods after a shock, until successive cohorts of slow investors arrive to trade, responding to then-higher expected returns on the security since their last rebalance.

In this sector, I show suggestive empirical evidence that the distribution of in-

[47]#Note to preliminary reader: This subsection is in the roughest state of all subsections of the paper, because it was written most recently. Apologies for things like sloppy notation and clunky equations.

creased holdings after a T-bill issuance surprise soon after the surprise differs from the distribution more than one week after the shock. Thinking of slow-moving capital such as Duffie (2010), this suggests that the investor sector with disproportionately *large* holdings after a T-bill supply shock serve as the fast investors in this setting.

To conduct this analysis, I use CUSIP-level end of month holdings data on money market mutual funds, reported to the SEC via the N-MFP reporting form, and made publicly available since 2012. Using end of month holdings data with my high frequency, weekly T-bill issuance surprise measurement has the disadvantage of fewer observations and some awkwardness in reconciling data sources of different frequency. However, the granular, CUSIP-level data in the N-MFP makes it possible to track individual money market funds' holdings of the *exact* T-bill that experiences surprise issuance. This is critical for my application, because a large portion of money market funds' T-bill holdings are in longer-term bills (such as the 6-month of 1-year maturity) that only very rarely experience issuance surprises.[48].

My empirical strategy in this section is to compare the money fund holdings effects of 4-Week T-bill issuance surprises from the very-recent past to those from the more-distant past. Because my money fund holdings data is at the end-of-month frequency, this will be an inherently monthly analysis. To manage this, I construct two different, monthly-frequency extensions of the weekly Wrightson 4-Week T-bill surprises. The first, Last Week 4W Surprise$_m$, is the end-of-month realization of the weekly T-bill surprise instrument used above. This is my proxy for more-recent T-bill supply shocks, relative to the end-of-month timing for holdings reports in the N-MFP form. The second, Monthly 4W T-Bill Surprise$_m$ is a measure of the *total* surprise in 4-Week T-bill issuance this month, relative to Wrightson's start-of-month projections. This construction leverages the fact that each week of Wrightson projections offers projections over the next 7-8 weeks of issuance, permitting construction of a sensible "monthly" issuance projection as of the information set of the beginning of the month. To formalize, I construct

$$
\begin{aligned}
&\text{Monthly 4W T-bill Surprise}_m = \\
&\text{First Week of Month, 4W Bill Issuance}_m - \mathbb{E}_{\text{Wrightson, m-1}}\left(\text{First Week of Month, 4W Bill Issuance}_m\right) \\
&+ \dots \\
&+ \text{Last Week of Month, 4W Bill Issuance}_m - \mathbb{E}_{\text{Wrightson, m-1}}\left(\text{Last Week of Month, 4W Bill Issuance}_m\right)
\end{aligned}
$$

I then estimate two different OLS regression results, using these measures. I estimate

[48]See the forecasting exercises of Section 6.3

$$\text{Original-Maturity 4-Week T-bill Holdings}_{s,m} =$$
$$\alpha_{s,1} + \rho_{s,1}\text{Original-Maturity 4-Week T-bill Holdings}_{s,m-1} + \gamma'_{s,1}X_{s,m-1}$$
$$+ \beta_{s,1}\text{Last Week 4w Surprise}_m + b_{s,1}\text{Expected Last Week 4w Issuance}_m + e_{s,m}$$

and

$$\text{Original-Maturity 4-Week T-bill Holdings}_{s,m} =$$
$$\alpha_{s,2} + \rho_{s,2}\text{Original-Maturity 4-Week T-bill Holdings}_{s,m-1} + \gamma'_{s,2}X_{s,m-1}$$
$$+ \beta_{s,2}\text{Monthly 4W T-bill Surprise}_m + b_{s,2}\text{Start of month expected 4w T-bill issuance}_m + e_{s,m}$$

for money market fund subsector s and month m. I aggregate the fund-level N-MFP holdings into sectors s of Prime, Treasury-only, and General Government funds. General government funds are able to hold short-term securities issued by the US Treasury or by US government agencies such as the FHLB, Fannie Mae, and Freddie Mac. They are also able to hold repurchase agreements that are collateralized by US Treasury or agency securities. I classify "Treasury only" funds as money market funds that hold, on average, more than 80% of their holdings in US Treasuries each month.[49] Prime money market funds can hold any security that a General Government fund can hold, as well as a host of private sector, highly-rated short term debt, such as commercial paper and certificates of deposit.[50]

Table 9 shows results for $\beta_{s,1}$ and $\beta_{s,2}$. The results suggest that the distribution of increased holdings after a very-recent T-bill issuance surprise is very different from the lower-frequency, monthly surprise measure. When looking only at 4-Week T-bill issuance surprises of the past week, a \$10 billion higher surprise T-bill issuance predicts a \$6.9 billion increase in 4-Week T-bill holdings of Treasury-only money market funds. This suggests that Treasury-only funds provide almost 70% of the total market elasticity, in the first week after a supply surprise. When looking at the monthly surprise measure, the numbers look very different. Treasury-only funds' holdings can account for 13% of the surprise increased 4-Week T-bill supply, at the monthly frequency. General government-only funds account for 23% of the

[49]Treasury only money market funds exist to cater to investors with mandates to only invest in US Treasury securities. Often, those investor mandates will have some restriction against investing in repurchase agreements collateralized in US Treasury securities.

[50]The lefthand side variable of Original-Maturity 4-Week T-bill Holdings$_{s,m}$ adds up the sector's holdings in all T-bills that were issued as 4-Week T-bills in that month. That is, it is the sum of the sector's holdings in the then-current 4-Week bill issued that week; the then-current 3-Week bill that was issued as a 4-week bill in the prior week; the then-current 2-week bill that was issued as a 4-Week bill two weeks prior; and the then-current 1-week bill that was issued as a 4-Week bill three weeks prior.

surprise increase. General government-only funds tend to hold similar magnitudes of T-bills as Treasury-only funds, but hold far greater total assets overall. Prime funds account for a smaller, but nontrivial, 7% of increase holdings.

	Treas	Treas	Gov	Gov	Prime	Prime
Last Week 4w Surpise	0.69^{**}		0.03		-0.17	
	0.32		0.42		0.17	
Monthly 4w Surprise		0.13^{**}		0.23^{***}		0.07^{**}
		0.06		0.05		0.03
R^2	0.43	0.44	0.77	0.80	0.65	0.66
N	108	109	108	109	108	109

Table 9: Money Market Fund Holdings Results

Importantly, Table 9 suggests that it is indeed the case that the universe of investors absorbing a supply shock varies in the *horizon* since the shock. The results even suggest an identity for the fast-moving investors described in Duffie (2010), as Treasury-only money market funds.

J Robustness of Core Results

Figure 24: LP-IV Impulse Response Estimates, Controlling for Lagged Surprises: Convenience Yield

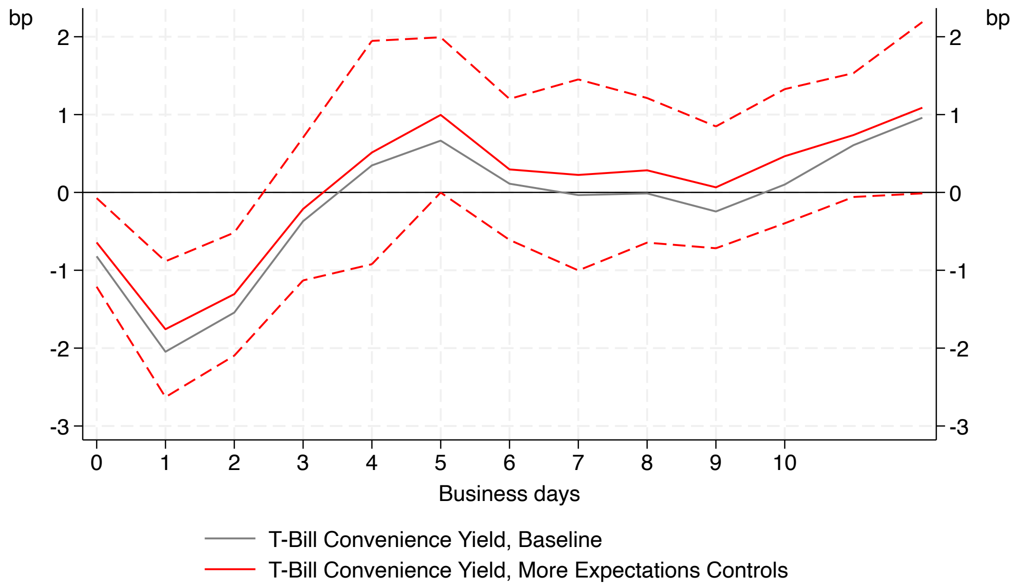


Figure 25: LP-IV Impulse Response Estimates, Controlling for Lagged Surprises: T-bill Supply

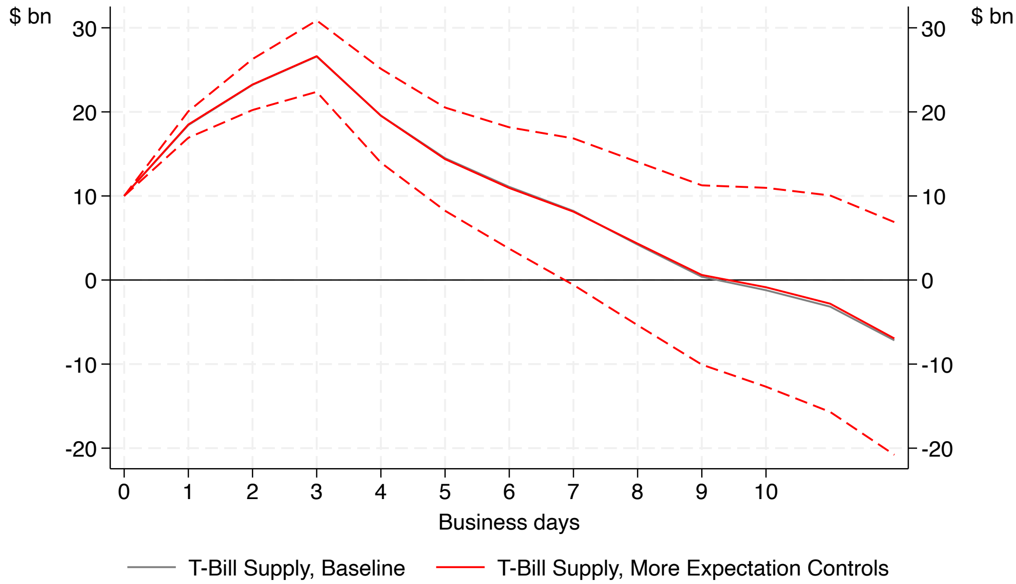


Figure 26: LP-IV Impulse Response Estimates, No Forward Projection Controls: Convenience Yield

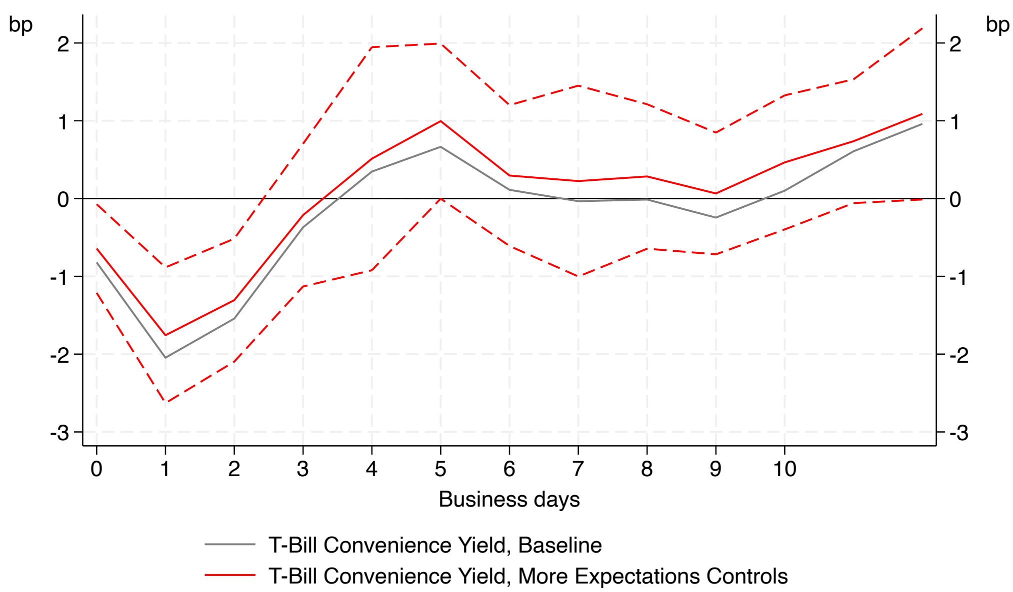


Figure 27: LP-IV Impulse Response Estimates, No Forward Projection Controls: T-bill Supply

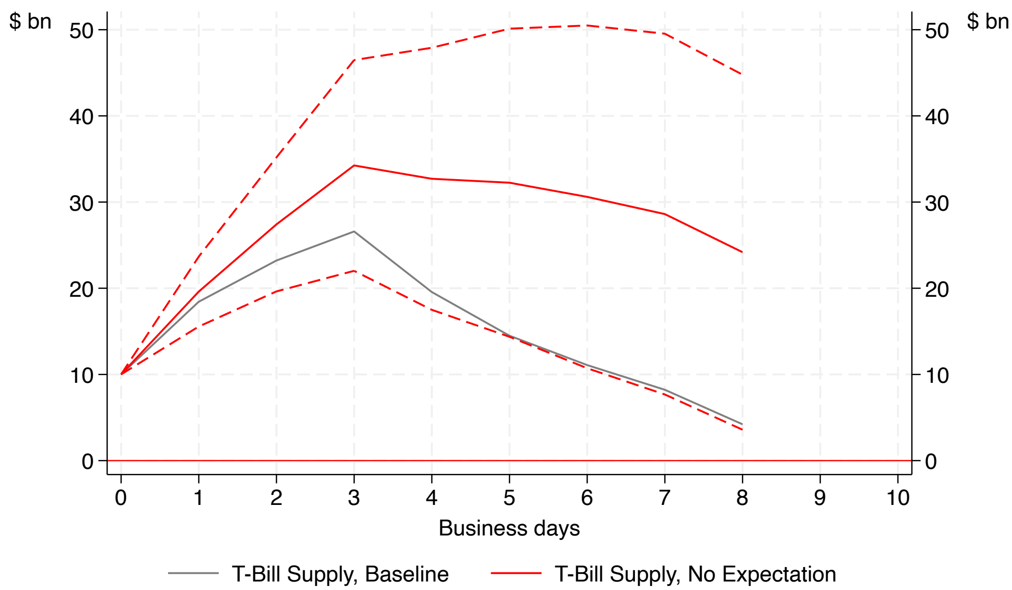


Figure 28: LP-IV Impulse Response Estimates, No Forward Projection Controls: Convenience Yield

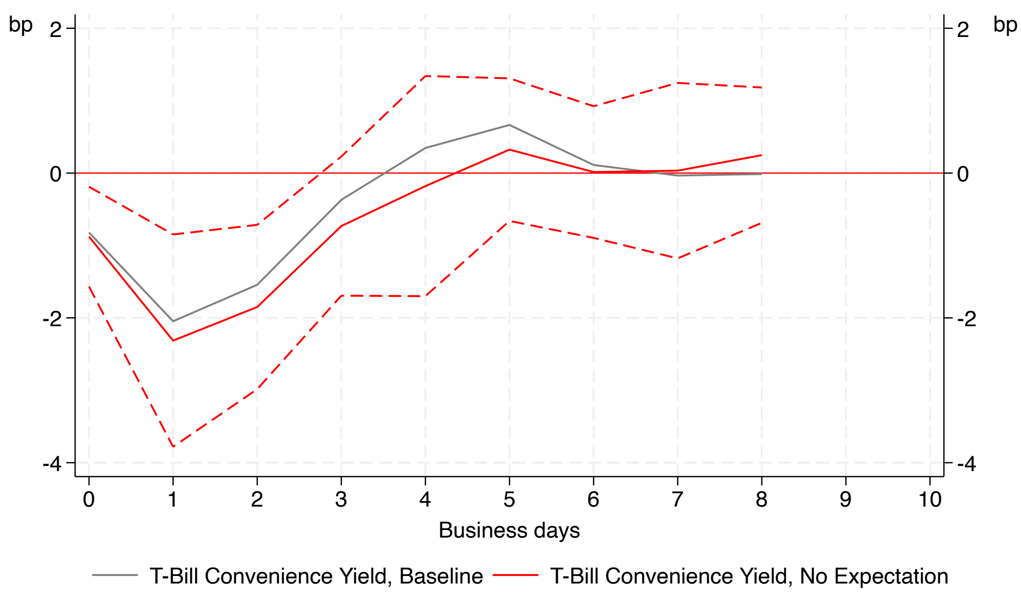


Figure 29: LP-IV Impulse Response Estimates, Tracking Individual CUSIPs

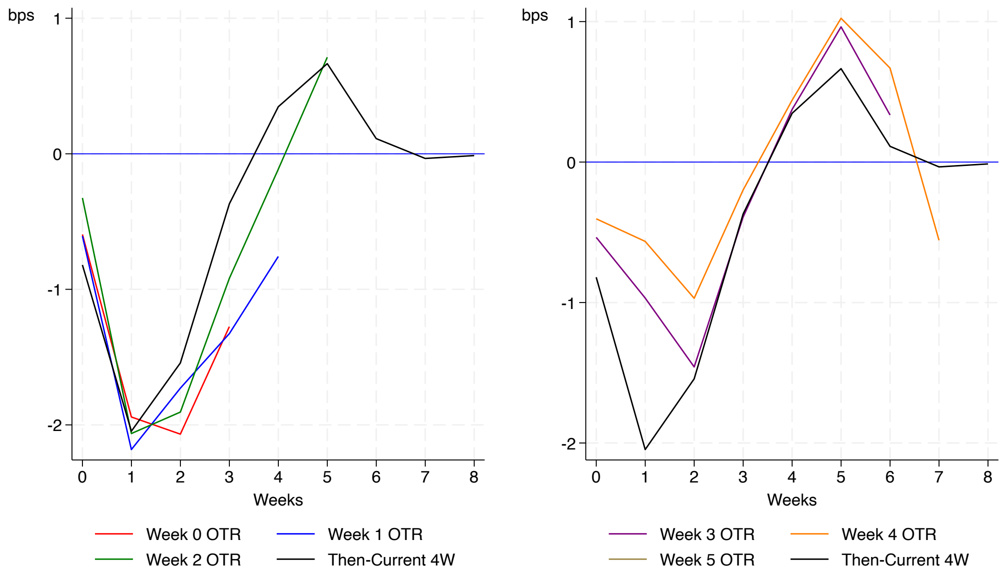
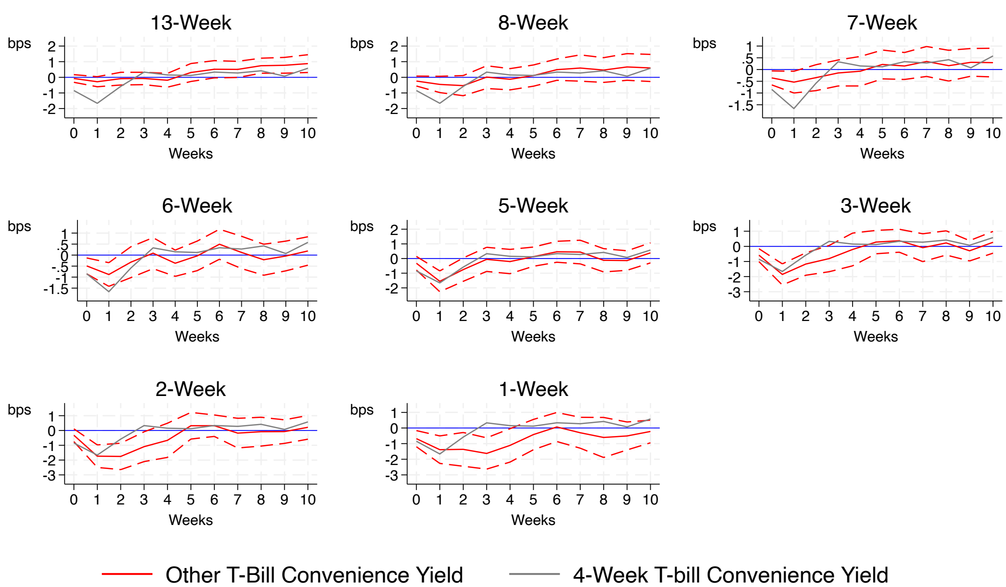


Figure 30: LP-IV Impulse Response Estimates, Across the Term Structure



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